Food Science

First edition | 10 units | 50 lessons · one school year | A video for every lesson

FIRST EDITION

Course guide

Food Science is a one-credit high-school laboratory science course taught in the kitchen. Over ten units the student studies water and heat, carbohydrates, proteins, fats and emulsions, fermentation, food safety and microbiology, preservation, taste, smell and the brain, and nutrition and food technology. Each lesson is built around real people and real moments: Nicolas Appert sealing bottles for Napoleon's navy, Count Rumford boiling water with a cannon borer, Louis-Camille Maillard heating sugars with amino acids, Louis Pasteur proving that yeast is alive, Fanny Hesse suggesting agar for Robert Koch's plates, John Snow mapping an outbreak, the Pillsbury scientists who wrote HACCP for astronaut food, Kikunae Ikeda tasting his kombu broth, and Wilbur Atwater measuring the energy in food.

Every lesson follows the same path. First comes **the story**; then **how they figured it out**: the question, the experiment and the evidence; then **the kitchen science** at a high-school level, with molecules, enzymes, microbes and heat transfer, and worked examples in real quantitative food science: $q = mc\Delta T$ and latent heat, Brix and baker's percentages, brine and pH, bacterial doubling, cooling rules, D-values and macronutrient energy. Last, **the kitchen lab**: a real investigation with a question, a hypothesis, controlled variables, a data table and a conclusion, wrapped around a full recipe the student cooks for the family. Practice sets, unit tests, a midterm and a final make it a complete course.

Food is treated as God's good gift, received with thanks and shared at the family table. We talk about food in terms of science, skill, safety, nourishment and hospitality, never body size or appearance. The course ends with a capstone: the student designs, runs and presents an original food-science experiment. *Fabricando fit faber*: by making, one becomes a maker, and by testing, one becomes a scientist.

> Most videos come from teaching sources chosen for high school: Harvard's Science and Cooking course (HarvardX), the American Chemical Society's Reactions, Amoeba Sisters, Khan Academy, TED-Ed, university extension services, government food-safety agencies,

> America's Test Kitchen and King Arthur Baking, plus careful science and history channels chosen lesson by lesson. Every video was previewed for accuracy, content and modest dress,. Some videos end with an invitation to subscribe or a link to a paid course; you can stop when the teaching ends. A few history videos show old photographs and newspaper pages.

Start with Lesson 1.1 →

Who it is for

Written for students in grades 9–12 who have completed or are taking Algebra I. Chemistry is helpful but not required; the chemistry needed is taught as it comes. Students work fairly independently with a parent checking work and at home for all stove, oven, knife and grill work. Required tools are an instant-read thermometer and a digital kitchen scale that reads grams; everything else is ordinary kitchen equipment and groceries, plus inexpensive pH strips.

How to use this course

1. **The weekly rhythm.** The course has 50 lessons in 10 units. Each lesson takes three sessions of about 50 minutes: (1) the warm-up, the video, the reading and the worked examples; (2) the kitchen lab, the recipe and the lab notebook (cooking days may run to 90 minutes); (3) the practice set and corrections. A unit test follows each unit, a midterm follows Unit 5 and a final follows Unit 10. At five sessions a week the course fills a school year.
2. **A parent supervises, and allergies come first.** A parent or responsible adult is at home for every lab and watches each new skill (the chef's knife, the stove, the oven, the broiler, the grill, the pressure cooker) before the student uses it alone. Before cooking, check every recipe and every tasting against your own family's food allergies; each recipe card names the major allergens it contains and offers swaps where they are easy.
3. **The high-school safety standard.** Students may use a chef's knife, the stove, oven, broiler and grill on their own once a parent has watched them do it safely, with a parent at home. There is no deep frying in this course (shallow pan-frying only). Adults light charcoal; students never use lighter fluid. Pressure cookers and boiling-water canning are used only with a parent present, and low-acid foods are

never home-canned. No raw dough, batter or raw eggs are tasted. Every lesson repeats the safety notes that matter for that lab.

4. **Story, science, lab.** Read the core ideas, then work the worked examples with a pencil before looking at the steps. In the lab, write the hypothesis before you start, change one variable at a time, and record what really happened. A lab that "fails" but is honestly recorded and explained earns full credit.
5. **Math.** Calculations use Algebra I: proportions, percentages, linear equations, exponents and scientific notation. Every answer carries its units. A calculator is allowed on all practice, tests and exams.
6. **Picture study.** Each lesson includes a public-domain painting, engraving or historic photograph tied to its story or science. Look at it for two minutes, then work through the "look for" items and questions.
7. **The lab notebook.** Use one bound notebook for the year. For each lab, record the date, question, hypothesis, variables, procedure, data with units, calculations, conclusion, sources of error, the recipe in your own words, and one improvement. The notebook is the record of a laboratory science credit.
8. **How we talk about food and bodies.** This course never discusses weight or how bodies look. Calories appear only as a unit of food energy, never as something to count or restrict. We use neutral words such as "nutrient-dense foods" and "treats." Treats and feasts are good gifts in their place.
9. **Groceries.** Most labs are a family meal or a side dish, so the course adds little to the grocery bill. Read the recipe card a few days ahead. A few labs need small extras: pH strips, a bag of dried beans, a head of cabbage for sauerkraut, a box of pectin.
10. **Optional books and tools.** Units list free government and extension resources and simple tools. They are extras; every lab can be done without them.
11. **Tests and unit projects.** Each unit ends with a 100-point test (calculations with worked answers, concepts and a short essay) and a unit project, a longer real-world investigation such as a family energy notebook, a fermentation log, a HACCP plan or a family food-safety audit.

Scope and sequence

UNIT 1 · WEEKS 1–4

The Science of Food and Safe Lab Practice

Food science as a discipline and the kitchen as a laboratory: measuring by mass, fair tests, safety with knives, heat, fire and sanitizer, calibrated thermometers, and a replicated popcorn experiment.

1.1 From Appert to the IFT: What Food Science Is

1.2 One Variable at a Time: The Cookie Experiment

1.3 Safe Lab Practice: Knives, Heat, Fire and Sanitizer

1.4 Fahrenheit, Celsius and the Calibrated Thermometer

1.5 James Lind's Fair Test and the Popcorn Experiment

UNIT 2 · WEEKS 4–7

Water and Heat

Water's polarity and hydrogen bonds, specific heat and $q = mc\Delta T$, latent heat and steam, pressure and the boiling point, and conduction, convection and radiation.

2.1 Water: The Molecule That Cooks

2.2 Count Rumford and Specific Heat

2.3 Joseph Black, Latent Heat and the Steam Burn

2.4 Denis Papin's Digester: Pressure and the Boiling Point

2.5 Conduction, Convection and Radiation: Percy Spencer's Melted Candy Bar

UNIT 3 · WEEKS 7–10

Carbohydrates

Sugars and Brix, caramelization and candy stages, starch gelatinization, retrogradation and staling, and fiber and digestion.

3.1 Sugars, Sweetness and Brix: Marggraf's Beet

3.2 Caramelization and the Candy Stages: Milton Hershey's Caramels

3.3 Starch and Gelatinization: Thomas Kingsford's Cornstarch

3.4 Retrogradation: Boussingault and the Stale Loaf

3.5 Fiber and Digestion: Beaumont's Window into the Stomach

UNIT 4 · WEEKS 10–13

Proteins

Amino acids and protein structure, foams, denaturation and the egg-safety line, the Maillard reaction, gluten, and collagen, gelatin and braising.

4.1 Amino Acids, Protein Structure and Foam: Emil Fischer's Peptides

4.2 Denaturation, Custard and the 160 °F Egg Line

4.3 The Maillard Reaction: Louis-Camille Maillard's Brown Crust

4.4 Gluten: Beccari's Sticky Discovery

4.5 Collagen, Gelatin and the Slow Braise

UNIT 5 · WEEKS 13–17

Fats and Emulsions

Fatty acids and melting points, butter, smoke points and shallow frying, emulsions and emulsifiers, flaky pastry, and Mège-Mouriès's margarine.

5.1 Fatty Acids and Butter: Chevreul's Fats

5.2 Smoke Points and Shallow Frying: David Wesson's Oil

5.3 Emulsions and Emulsifiers: Gobley's Lecithin

5.4 Shortening and Flakiness: Crisco and the Pie Crust

5.5 Mège-Mouriès and Margarine

UNIT 6 · WEEKS 17–20

Microbes I: Fermentation

Pasteur and fermentation, yeast biology and oven spring, sourdough, lactic fermentation in sauerkraut, and acetic acid in vinegar.

6.1 Pasteur Proves Fermentation Is Alive

6.2 Yeast Biology and Oven Spring: The Fleischmann Brothers

6.3 Sourdough: Wild Yeast, Lactic Acid Bacteria and the Gold Rush

6.4 Lactic Fermentation: Captain Cook's Sauerkraut

6.5 Vinegar and Acetic Acid: Dip Thy Morsel

UNIT 7 · WEEKS 20–23

Microbes II: Food Safety

Pathogens, growth curves and FAT TOM, outbreak investigation from John Snow to E. coli O157:H7, HACCP, and cooling rules and the cold chain.

7.1 Bacteria, Viruses and Parasites: Salmon and Smith's Bacillus

7.2 Growth Curves and FAT TOM: Fanny Hesse's Agar

7.3 Outbreak Detectives: John Snow to E. coli O157:H7

7.4 HACCP: Safe Food for Astronauts

7.5 The Cold Chain and Safe Leftovers: Frederick McKinley Jones

UNIT 8 · WEEKS 23–26

Preservation

Drying and water activity, salt, sugar and osmosis, pH 4.6 and botulism, canning and pasteurization, and freezing and ice crystals.

8.1 Drying and Water Activity: W. J. Scott's Discovery

8.2 Salt, Sugar and Osmosis: The Salt of the Earth

8.3 Acid and pH 4.6: Van Ermengem and the Botulism Line

8.4 Canning and Pasteurization: Nathan Straus's Milk Stations

8.5 Freezing and Ice Crystals: Clarence Birdseye

UNIT 9 · WEEKS 27–30

Taste, Smell and the Brain

Taste receptors and the tongue-map myth, umami, smell and flavor, the genetics of taste, and the brain's reward system, cravings and satiety.

9.1 Taste Receptors and the Tongue-Map Myth

9.2 Ikeda and Umami

9.3 Smell and Flavor: Buck, Axel and the Receptor Genes

9.4 Genetics of Taste: Fox's PTC and Bartoshuk's Supertasters

9.5 Reward, Cravings and Satiety: Olds, Milner and the Bliss Point

UNIT 10 · WEEKS 30–33

Nutrition Science and Food Technology

Atwater and food energy, the vitamins, the Nutrition Facts label, food additives and GRAS, food technology and space food, and an original capstone experiment.

10.1 Atwater's Calorimeter: Measuring Food Energy

10.2 The Vitamins: Funk, McCollum and Vitamin C

10.3 The Nutrition Facts Label and the Dietary Guidelines

10.4 Food Additives and GRAS: Harvey Wiley's Poison Squad

10.5 Food Technology and the Capstone: Freeze-Dried Space Food

Weekly pacing calendar

WEEK	PLAN
1	• Day 1: Lesson 1.1 From Appert to the IFT: What Food Science Is: video, teaching and worked examples • Day 2: Lesson 1.1: kitchen lab and notebook • Day 3: Lesson 1.1: practice set and corrections • Day 4: Lesson 1.2 One Variable at a Time: The Cookie Experiment: video, teaching and worked examples • Day 5: Lesson 1.2: kitchen lab and notebook *Five sessions a week of about 50 minutes. Families on a four-day week can combine the practice day of one lesson with the teaching day of the next.*
2	• Day 1: Lesson 1.2: practice set and corrections • Day 2: Lesson 1.3 Safe Lab Practice: Knives, Heat, Fire and Sanitizer: video, teaching and worked examples • Day 3: Lesson 1.3: kitchen lab and notebook • Day 4: Lesson 1.3: practice set and corrections • Day 5: Lesson 1.4 Fahrenheit, Celsius and the Calibrated Thermometer: video, teaching and worked examples
3	• Day 1: Lesson 1.4: kitchen lab and notebook • Day 2: Lesson 1.4: practice set and corrections • Day 3: Lesson 1.5 James Lind's Fair Test and the Popcorn Experiment: video, teaching and worked examples • Day 4: Lesson 1.5: kitchen lab and notebook • Day 5: Lesson 1.5: practice set and corrections
4	• Day 1: Unit 1 test • Day 2: Lesson 2.1 Water: The Molecule That Cooks: video, teaching and worked examples • Day 3: Lesson 2.1: kitchen lab and notebook • Day 4: Lesson 2.1: practice set and corrections • Day 5: Lesson 2.2 Count Rumford and Specific Heat: video, teaching and worked examples
5	• Day 1: Lesson 2.2: kitchen lab and notebook • Day 2: Lesson 2.2: practice set and corrections

WEEK	PLAN
	• Day 3: Lesson 2.3 Joseph Black, Latent Heat and the Steam Burn: video, teaching and worked examples • Day 4: Lesson 2.3: kitchen lab and notebook • Day 5: Lesson 2.3: practice set and corrections
6	• Day 1: Lesson 2.4 Denis Papin's Digester: Pressure and the Boiling Point: video, teaching and worked examples • Day 2: Lesson 2.4: kitchen lab and notebook • Day 3: Lesson 2.4: practice set and corrections • Day 4: Lesson 2.5 Conduction, Convection and Radiation: Percy Spencer's Melted Candy Bar: video, teaching and worked examples • Day 5: Lesson 2.5: kitchen lab and notebook
7	• Day 1: Lesson 2.5: practice set and corrections • Day 2: Unit 2 test • Day 3: Lesson 3.1 Sugars, Sweetness and Brix: Marggraf's Beet: video, teaching and worked examples • Day 4: Lesson 3.1: kitchen lab and notebook • Day 5: Lesson 3.1: practice set and corrections
8	• Day 1: Lesson 3.2 Caramelization and the Candy Stages: Milton Hershey's Caramels: video, teaching and worked examples • Day 2: Lesson 3.2: kitchen lab and notebook • Day 3: Lesson 3.2: practice set and corrections • Day 4: Lesson 3.3 Starch and Gelatinization: Thomas Kingsford's Cornstarch: video, teaching and worked examples • Day 5: Lesson 3.3: kitchen lab and notebook
9	• Day 1: Lesson 3.3: practice set and corrections • Day 2: Lesson 3.4 Retrogradation: Boussingault and the Stale Loaf: video, teaching and worked examples • Day 3: Lesson 3.4: kitchen lab and notebook • Day 4: Lesson 3.4: practice set and corrections • Day 5: Lesson 3.5 Fiber and Digestion: Beaumont's Window into the Stomach: video, teaching and worked examples
10	• Day 1: Lesson 3.5: kitchen lab and notebook • Day 2: Lesson 3.5: practice set and corrections

WEEK	PLAN
	• Day 3: Unit 3 test • Day 4: Lesson 4.1 Amino Acids, Protein Structure and Foam: Emil Fischer's Peptides: video, teaching and worked examples • Day 5: Lesson 4.1: kitchen lab and notebook
11	• Day 1: Lesson 4.1: practice set and corrections • Day 2: Lesson 4.2 Denaturation, Custard and the 160 °F Egg Line: video, teaching and worked examples • Day 3: Lesson 4.2: kitchen lab and notebook • Day 4: Lesson 4.2: practice set and corrections • Day 5: Lesson 4.3 The Maillard Reaction: Louis-Camille Maillard's Brown Crust: video, teaching and worked examples
12	• Day 1: Lesson 4.3: kitchen lab and notebook • Day 2: Lesson 4.3: practice set and corrections • Day 3: Lesson 4.4 Gluten: Beccari's Sticky Discovery: video, teaching and worked examples • Day 4: Lesson 4.4: kitchen lab and notebook • Day 5: Lesson 4.4: practice set and corrections
13	• Day 1: Lesson 4.5 Collagen, Gelatin and the Slow Braise: video, teaching and worked examples • Day 2: Lesson 4.5: kitchen lab and notebook • Day 3: Lesson 4.5: practice set and corrections • Day 4: Unit 4 test • Day 5: Lesson 5.1 Fatty Acids and Butter: Chevreul's Fats: video, teaching and worked examples
14	• Day 1: Lesson 5.1: kitchen lab and notebook • Day 2: Lesson 5.1: practice set and corrections • Day 3: Lesson 5.2 Smoke Points and Shallow Frying: David Wesson's Oil: video, teaching and worked examples • Day 4: Lesson 5.2: kitchen lab and notebook • Day 5: Lesson 5.2: practice set and corrections
15	• Day 1: Lesson 5.3 Emulsions and Emulsifiers: Gobley's Lecithin: video, teaching and worked examples • Day 2: Lesson 5.3: kitchen lab and notebook

WEEK	PLAN
	• Day 3: Lesson 5.3: practice set and corrections • Day 4: Lesson 5.4 Shortening and Flakiness: Crisco and the Pie Crust: video, teaching and worked examples • Day 5: Lesson 5.4: kitchen lab and notebook
16	• Day 1: Lesson 5.4: practice set and corrections • Day 2: Lesson 5.5 Mège-Mouriès and Margarine: video, teaching and worked examples • Day 3: Lesson 5.5: kitchen lab and notebook • Day 4: Lesson 5.5: practice set and corrections • Day 5: Unit 5 test
17	• Day 1: Review day for the midterm • Day 2: Midterm exam • Day 3: Lesson 6.1 Pasteur Proves Fermentation Is Alive: video, teaching and worked examples • Day 4: Lesson 6.1: kitchen lab and notebook • Day 5: Lesson 6.1: practice set and corrections
18	• Day 1: Lesson 6.2 Yeast Biology and Oven Spring: The Fleischmann Brothers: video, teaching and worked examples • Day 2: Lesson 6.2: kitchen lab and notebook • Day 3: Lesson 6.2: practice set and corrections • Day 4: Lesson 6.3 Sourdough: Wild Yeast, Lactic Acid Bacteria and the Gold Rush: video, teaching and worked examples • Day 5: Lesson 6.3: kitchen lab and notebook
19	• Day 1: Lesson 6.3: practice set and corrections • Day 2: Lesson 6.4 Lactic Fermentation: Captain Cook’s Sauerkraut: video, teaching and worked examples • Day 3: Lesson 6.4: kitchen lab and notebook • Day 4: Lesson 6.4: practice set and corrections • Day 5: Lesson 6.5 Vinegar and Acetic Acid: Dip Thy Morsel: video, teaching and worked examples
20	• Day 1: Lesson 6.5: kitchen lab and notebook • Day 2: Lesson 6.5: practice set and corrections • Day 3: Unit 6 test

WEEK	PLAN
	• Day 4: Lesson 7.1 Bacteria, Viruses and Parasites: Salmon and Smith's Bacillus: video, teaching and worked examples • Day 5: Lesson 7.1: kitchen lab and notebook
21	• Day 1: Lesson 7.1: practice set and corrections • Day 2: Lesson 7.2 Growth Curves and FAT TOM: Fanny Hesse's Agar: video, teaching and worked examples • Day 3: Lesson 7.2: kitchen lab and notebook • Day 4: Lesson 7.2: practice set and corrections • Day 5: Lesson 7.3 Outbreak Detectives: John Snow to E. coli O157:H7: video, teaching and worked examples
22	• Day 1: Lesson 7.3: kitchen lab and notebook • Day 2: Lesson 7.3: practice set and corrections • Day 3: Lesson 7.4 HACCP: Safe Food for Astronauts: video, teaching and worked examples • Day 4: Lesson 7.4: kitchen lab and notebook • Day 5: Lesson 7.4: practice set and corrections
23	• Day 1: Lesson 7.5 The Cold Chain and Safe Leftovers: Frederick McKinley Jones: video, teaching and worked examples • Day 2: Lesson 7.5: kitchen lab and notebook • Day 3: Lesson 7.5: practice set and corrections • Day 4: Unit 7 test • Day 5: Lesson 8.1 Drying and Water Activity: W. J. Scott's Discovery: video, teaching and worked examples
24	• Day 1: Lesson 8.1: kitchen lab and notebook • Day 2: Lesson 8.1: practice set and corrections • Day 3: Lesson 8.2 Salt, Sugar and Osmosis: The Salt of the Earth: video, teaching and worked examples • Day 4: Lesson 8.2: kitchen lab and notebook • Day 5: Lesson 8.2: practice set and corrections
25	• Day 1: Lesson 8.3 Acid and pH 4.6: Van Ermengem and the Botulism Line: video, teaching and worked examples • Day 2: Lesson 8.3: kitchen lab and notebook • Day 3: Lesson 8.3: practice set and corrections

WEEK	PLAN
	• Day 4: Lesson 8.4 Canning and Pasteurization: Nathan Straus's Milk Stations: video, teaching and worked examples • Day 5: Lesson 8.4: kitchen lab and notebook
26	• Day 1: Lesson 8.4: practice set and corrections • Day 2: Lesson 8.5 Freezing and Ice Crystals: Clarence Birdseye: video, teaching and worked examples • Day 3: Lesson 8.5: kitchen lab and notebook • Day 4: Lesson 8.5: practice set and corrections • Day 5: Unit 8 test
27	• Day 1: Lesson 9.1 Taste Receptors and the Tongue-Map Myth: video, teaching and worked examples • Day 2: Lesson 9.1: kitchen lab and notebook • Day 3: Lesson 9.1: practice set and corrections • Day 4: Lesson 9.2 Ikeda and Umami: video, teaching and worked examples • Day 5: Lesson 9.2: kitchen lab and notebook
28	• Day 1: Lesson 9.2: practice set and corrections • Day 2: Lesson 9.3 Smell and Flavor: Buck, Axel and the Receptor Genes: video, teaching and worked examples • Day 3: Lesson 9.3: kitchen lab and notebook • Day 4: Lesson 9.3: practice set and corrections • Day 5: Lesson 9.4 Genetics of Taste: Fox's PTC and Bartoshuk's Supertasters: video, teaching and worked examples
29	• Day 1: Lesson 9.4: kitchen lab and notebook • Day 2: Lesson 9.4: practice set and corrections • Day 3: Lesson 9.5 Reward, Cravings and Satiety: Olds, Milner and the Bliss Point: video, teaching and worked examples • Day 4: Lesson 9.5: kitchen lab and notebook • Day 5: Lesson 9.5: practice set and corrections
30	• Day 1: Unit 9 test • Day 2: Lesson 10.1 Atwater's Calorimeter: Measuring Food Energy: video, teaching and worked examples • Day 3: Lesson 10.1: kitchen lab and notebook • Day 4: Lesson 10.1: practice set and corrections

WEEK	PLAN
	• Day 5: Lesson 10.2 The Vitamins: Funk, McCollum and Vitamin C: video, teaching and worked examples
31	• Day 1: Lesson 10.2: kitchen lab and notebook • Day 2: Lesson 10.2: practice set and corrections • Day 3: Lesson 10.3 The Nutrition Facts Label and the Dietary Guidelines: video, teaching and worked examples • Day 4: Lesson 10.3: kitchen lab and notebook • Day 5: Lesson 10.3: practice set and corrections
32	• Day 1: Lesson 10.4 Food Additives and GRAS: Harvey Wiley's Poison Squad: video, teaching and worked examples • Day 2: Lesson 10.4: kitchen lab and notebook • Day 3: Lesson 10.4: practice set and corrections • Day 4: Lesson 10.5 Food Technology and the Capstone: Freeze-Dried Space Food: video, teaching and worked examples • Day 5: Lesson 10.5: kitchen lab and notebook
33	• Day 1: Lesson 10.5: practice set and corrections • Day 2: Unit 10 test • Day 3: Review day for the final • Day 4: Final exam

Materials

An instant-read food thermometer (required)

Used in nearly every lab. Calibrated in Lesson 1.4.

A digital kitchen scale that reads grams (required)

Used in every lab. A model that reads 0.1 g helps with salt, yeast and small samples but is not required.

Measuring cups (dry and liquid), measuring spoons and a timer

For recipes and timed observations.

A bound lab notebook and a scientific calculator

The notebook is the year's record of a laboratory science credit.

pH test strips (range about 1–14, or 2–9)

Inexpensive; used in the fermentation, vinegar and preservation labs.

A refrigerator thermometer

For the food-safety and cold-chain labs.

Ordinary pots, pans and sheet pans; a chef's knife, a paring knife and two cutting boards

One board for raw meat and one for ready-to-eat foods.

Clean glass jars with lids

For solutions, sourdough starter, sauerkraut and pickles.

Optional: a candy thermometer, a stand or hand mixer, a cast-iron skillet, a pressure cooker, a grill

Useful but not required. The candy thermometer is used only for sugar work.

Grading

Grades come from practice sets, kitchen labs, the lab notebook, ten unit tests, a midterm and a final. Labs are graded on safety, technique, measurement and honest records, not on whether the dish came out perfect.

PART	%
Practice sets (completed and corrected)	**15**
Kitchen labs (safety, technique, measurement, analysis)	**25**
Lab notebook (organization, honesty, error discussion)	**10**
Unit tests	**30**
Midterm exam	**10**
Final exam	**10**

Scale: A 90–100, B 80–89, C 70–79, D 60–69, F below 60.

- Practice sets are graded for completion and correction: a problem done, checked and correctly reworked earns full credit.

- On tests, give partial credit for a correct formula and setup with units even if the arithmetic slips. A missing unit costs a point; an answer with no work earns at most half credit.
- A lab earns full marks when it has a hypothesis with a reason, a data table with units, correct calculations, a conclusion that answers the question, and a specific paragraph on error and improvement. A dish that flops but is honestly recorded and explained earns full credit.
- Never grade or comment on anyone's body, size or how much they ate. Grades rest on science, safety, care and improvement.
- For a transcript, this course is one full credit of laboratory science (food science or chemistry of foods). Keep the lab notebook, unit projects and exams as the record of the year.

A NOTE TO PARENTS

You do not need to be a chemist or a chef to teach this course. Read the lesson, watch the video with your student when you can, and be the lab partner and safety officer: be at home for every lab, watch each new skill once before your student does it alone, and ask the two questions every science teacher asks: "What do you predict?" and "How do you know?" The answer keys for the practice sets, tests and exams are in the lessons.

Expect some labs to give surprising results. Bread will rise less than planned; a sauce will break; popcorn will refuse to pop. In a laboratory course that is not failure but data. The grading rewards honest records and good explanations, and the lessons often ask the student to repeat a lab with one improvement.

Food in this course is a good gift, studied with wonder and shared with thanks. We keep the conversation on science, skill, nourishment and hospitality, never on weight or appearance. Teenagers are growing and need plenty of good food. Food allergies and any medical diets belong to your family and your doctor: please read each recipe card's allergen note and make the swaps your family needs.

UNIT 1

The Science of Food and Safe Lab Practice

Food science began in a confectioner's kitchen and grew into a field of chemists, microbiologists and engineers. In this first unit you will learn to work like a food scientist in your own kitchen: measuring by mass, changing one variable at a time, calibrating instruments, working safely with knives, heat and fire, and writing up what you did so someone else could repeat it.

Each lesson pairs a real story with a lab and a recipe: Nicolas Appert's sealed bottles and a banana bread baked entirely by weight; Ruth Wakefield's Toll House cookie and a butter experiment; George Manby's extinguisher, the fire triangle and a stir-fry; Fahrenheit and Celsius and a calibrated thermometer in roasted chicken thighs; and James Lind's scurvy trial with a replicated popcorn experiment. By the end you will have a lab notebook set up for the year and the habits that make every later lab safe and trustworthy.

PREREQUISITES

- Algebra I (or taking it now): solving simple equations, working with fractions, decimals and percentages
- Has used a stove and oven with a parent; this unit sets the safety standard for the year
- Has a digital kitchen scale that reads grams and an instant-read thermometer

MASTERY CHECKLIST

- ☐ I can tell how food science grew from Appert's practical discovery to a scientific field, and why scientists measure by mass.
- ☐ I can design a fair test with independent, dependent and controlled variables, and replicate it.
- ☐ I can calculate a mean, range, percent error, percent difference and a yield factor.
- ☐ I can explain the fire triangle, handle a grease fire correctly, use the claw and bridge grips, and mix a measured sanitizer.
- ☐ I can convert between °F and °C, calibrate a thermometer, and cook poultry to 165 °F.
- ☐ I can write a complete lab report.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FoodSafety.gov: Safe Minimum Internal Temperatures**: Free at FoodSafety.gov. A chart to tape inside a cupboard door; used all year.
- **King Arthur Baking: Ingredient Weight Chart**: Free. Grams per cup for hundreds of ingredients; the source of this course's 120 g cup of flour.
- **A digital kitchen scale that reads in 1-gram steps**: Required for the course. A model that reads 0.1 g is helpful for salt, yeast and the popcorn lab but not necessary.
- **A small ABC or BC fire extinguisher for the kitchen**: Many families already have one. Learn the PASS method (pull, aim, squeeze, sweep) with a parent.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

1.1	**From Appert to the IFT: What Food Science Is**	3 sessions of 50–90 minutes
1.2	**One Variable at a Time: The Cookie Experiment**	3 sessions of 50–90 minutes
1.3	**Safe Lab Practice: Knives, Heat, Fire and Sanitizer**	3 sessions of 50–90 minutes
1.4	**Fahrenheit, Celsius and the Calibrated Thermometer**	3 sessions of 50–90 minutes
1.5	**James Lind's Fair Test and the Popcorn Experiment**	3 sessions of 50–90 minutes

Unit 1 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   Why did Appert's bottled foods keep, and who explained it, and when?

2. **6 pts**

   Five scoops of flour weigh 136, 141, 139, 144 and 140 g. Find the mean, the range and the percent error compared with 120 g.

3. **6 pts**

   Convert 2 lb of flour to grams (1 lb = 453.6 g) and then to cups at 120 g per cup.

4. **7 pts**

   A student tests whether chilling dough changes cookie spread. Name the independent variable, two dependent variables, and four controlled variables, and write a hypothesis.

5. **6 pts**

   Scale a 36-cookie recipe that uses 270 g flour and 200 g sugar to make 90 cookies.

6. **6 pts**

   Batch A cookies have a mean diameter of 6.8 cm; batch B, 8.0 cm. Find the percent difference.

7. **8 pts**

   Describe step by step what you should do if oil catches fire in a skillet, and explain with the fire triangle why water must never be used.

8. **6 pts**

   You mix 1 tablespoon (15 mL) of 8.25% bleach into 1 gallon (3,785 mL) of water. Find the sodium hypochlorite concentration in ppm.

9. **4 pts**

   Why should you never mix bleach with vinegar or ammonia?

10. **6 pts**

    Convert 160 °F and 145 °F to Celsius, and say what each is the safe minimum for.

11. **6 pts**

    Estimate the boiling point of water at 6,000 ft in °F and °C.

12. **7 pts**

    A thermometer reads 35 °F in ice water and 211 °F in boiling water at sea level. What is the true temperature when it reads 165 °F?

13. **6 pts**

    Describe Lind's 1747 trial: the subjects, the groups, and the result.

14. **6 pts**

    In the popcorn lab, 50.0 g of dried kernels leave 14.0 g unpopped, and 50.0 g of control kernels leave 4.0 g. Find each percent popped.

15. **4 pts**

    Explain why replication matters, using the popcorn lab.

16. **10 pts**

    Short essay (5–7 sentences): Choose one kitchen habit in your family (for example, how rice is cooked or how cookies are baked). Design a fair test that would improve it: state the question, hypothesis, independent, dependent and controlled variables, how many trials, and what you would measure.

ANSWER KEY

1. Heating the sealed bottles killed the microbes inside, and the seal kept new ones out. Appert did not know this; Louis Pasteur showed in the 1860s that microbes cause spoilage.
2. Mean $700/5 = 140$ g; range $144 - 136 = 8$ g; percent error $20/120 \times 100\% = 16.7\%$.
3. 907 g; $907/120 \approx 7.6$ cups.
4. Independent: chilled or not chilled. Dependent: diameter and thickness. Controlled: recipe, dough-ball mass, pan, oven temperature, baking time, rack position. Hypothesis: If the dough is chilled, the cookies will spread less, because the butter takes longer to melt and the proteins and starch set first.
5. Yield factor $90/36 = 2.5$; flour 675 g, sugar 500 g.
6. $1.2/7.4 \times 100\% = 16.2\%$
7. Turn off the burner, slide a lid or baking sheet over the pan and leave it; use baking soda for a small fire; if it grows, get out and call 911. This removes heat and oxygen. Water sinks under the oil, flashes to steam and throws burning oil outward.
8. $0.0825 \times 15 = 1.24$ mL; $1.24/3800 \times 10^6 \approx 326$ ppm. Use less bleach (about 2 tsp) for about 200–240 ppm.
9. The mixtures release toxic gases (chlorine with acids, chloramines with ammonia).
10. 71 °C: ground beef, pork, lamb and egg dishes. 63 °C: whole cuts of beef, pork, veal and lamb (with a 3-minute rest) and fish.
11. $212 - 12 = 200$ °F; $\frac{5}{9}(168) = 93$ °C.
12. Span 176 vs. true 180: $T = 32 + \frac{180}{176}(165 - 35) = 32 + 133.0 = 165.0$ °F. (It happens to be right at this point.)
13. Twelve sailors with similar scurvy, same meals, six pairs each given a different remedy (cider, elixir of vitriol, vinegar, sea water, spice paste, oranges and lemons). The pair given citrus recovered fastest.
14. Dried $36/50 = 72\%$; control $46/50 = 92\%$.
15. Results vary by chance from trial to trial. Repeating each treatment shows the size of that scatter, so you can tell whether a difference between treatments is real.

16. Answers vary. Full credit for a clear testable question, a hypothesis with a reason, one independent variable, a measurable dependent variable, at least three controlled variables, replication, and a plan for analysis.

UNIT PROJECT: MY KITCHEN LAB MANUAL

Assemble the front section of your lab notebook as a manual for the year: your family kitchen safety audit (with fixes made), your thermometer calibration record, a one-page fire and burn response card to post inside a cupboard door, and a clean copy of your best lab report from this unit.

Then design and run one new fair test of your own on a simple recipe from this unit (for example, chilled vs. unchilled cookie dough, or two brands of popcorn) with at least two trials per treatment, and write a complete report with a data table, calculations and a conclusion.

LOOK FOR	WHAT IT MEANS
Safety	Audit completed honestly with real fixes; fire and burn card accurate (lid, heat off, never water; cool running water for minor burns).
Measurement	Masses in grams, temperatures calibrated and converted correctly, units on every number.
Experimental design	One independent variable, controlled variables listed, replication, alternating trials where it matters.
Analysis and honesty	Correct means, ranges and percent differences; results reported as they happened, including surprises.
Report and cleanup	Complete, readable report; kitchen left clean and sanitized after every lab.

1.1 From Appert to the IFT: What Food Science Is

OBJECTIVES

- Tell how Nicolas Appert's sealed jars (1795–1810) began food science before anyone knew why they worked, and how the field grew into the Institute of Food Technologists (1939).
- Explain why scientists and bakers measure by mass, and calculate a mean, a range and a percent error from repeated measurements.
- Bake a quick bread entirely by weight and record it as a lab, not just a recipe.

> **Warm-up.** Scoop a cup of flour from the bag three different ways: dip and sweep, spoon in and level, and pack it down. Before weighing anything, guess: will the three cups weigh the same? Write your guesses down.

WATCH

Weight vs. Volume Measurement - Joyofbaking.com

Joy of Baking · 10:31

https://www.youtube.com/watch?v=nF3vFMYOM8Y

> **WHEN TO WATCH**
> During session 1, before the scooping lab. Watch how much the weight of one "cup" of flour changes with the way it is filled.

Note: A baking teacher's demonstration. Her conversions are good; this course uses 120 g for a cup of all-purpose flour.

BACKUP VIDEO

What is Food Science?

Bumpers College at the University of Arkansas · 2:06

https://www.youtube.com/watch?v=_bJYav37-zw

Any time in this unit. A short look inside a university food-science department: sensory panels, microbiology, food processing and product development.

KEY TERMS

food science

The study of the physical, chemical and biological nature of foods and of what happens to them when they are grown, stored, processed, cooked and eaten.

mass

The amount of matter in an object, measured in grams (g) or kilograms. A kitchen scale measures mass; a measuring cup measures volume.

mean

The average of a set of measurements: add them and divide by how many there are.

range

The largest measurement minus the smallest. A quick sign of how much the measurements scatter.

percent error

How far a measured value is from an accepted value, as a percentage of the accepted value.

quick bread

A bread raised by baking soda or baking powder instead of yeast, so it can be mixed and baked at once.

CORE IDEAS

The story. In the 1790s France was at war, and its army and navy could carry food only if it was dried, salted or smoked. A Paris confectioner named Nicolas Appert began experimenting with something new: he packed cooked foods into thick glass bottles, corked and wired them shut, and heated the sealed bottles in boiling water. In 1810 the French government awarded him a prize of 12,000 francs, and that same year he published *The Art of Preserving All Kinds of Animal and Vegetable Substances for Several Years*, giving the method to the world.

How they figured it out. Appert worked by careful trial and observation for about fifteen years: how long to heat, how full to fill, how tightly to seal. He did not know *why* his bottles kept food from spoiling; he thought the heat and the sealing kept out air. Half a century later Louis Pasteur showed that microbes cause spoilage and that heat kills them, and the explanation caught up with the practice. That pattern, careful practice first and then the science that explains it and improves it, is the whole history of food science. By the 1930s canning, freezing and packaged foods had grown into large industries, and in 1939 the scientists who studied them founded the Institute of Food Technologists (IFT), which still gathers food scientists today.

The kitchen science. A food scientist measures. The most important habit is measuring by **mass**, not volume. A cup is a volume, and how much flour fits in it depends on how tightly the flour is packed: a dipped-and-swept cup of all-purpose flour often weighs 140–150 g, while a spooned-and-leveled cup weighs closer to 120 g. That is a difference of 15–25 percent, enough to turn a moist bread into a dry one. A gram is a gram however it is scooped. When you repeat a measurement several times, report the **mean** and the **range**, and compare your mean with an accepted value using **percent error**. This course uses 120 g as the accepted mass of one cup of all-purpose flour, the figure King Arthur Baking uses.

Think it through. Science is not only in laboratories with white coats. Every time you change one thing in a recipe on purpose and notice what happens, you are doing what Appert did. The difference this year is that you will write it down the way a scientist does: a question, a prediction, a measurement, a result and a conclusion.

Let's cook. You will bake a loaf of banana bread with every ingredient weighed in grams. The skill is **taring the scale** (setting it to zero with the bowl on it) and adding each ingredient straight into the bowl. It is faster, more accurate and leaves fewer dishes.

PICTURE STUDY



Portrait of Nicolas Appert, Unknown engraver, 19th century · Engraving · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Nicolas Appert (1749–1841) was a confectioner, a maker of sweets and preserves, not a trained scientist. His careful bottling experiments fed sailors and soldiers, and they began the long road from the kitchen to the food laboratory.

Look closely

- Look at his clothing. What does it tell you about when he lived?
- Look at his face. What qualities would a man need to repeat the same experiment for fifteen years?
- Imagine the room behind him: bottles, corks, wire, kettles of boiling water. What would you expect to see on his workbench?

Talk about it

1. Appert solved a practical problem without knowing the science underneath. Can you think of another kitchen practice people followed long before they knew why it worked?
2. Why might a confectioner, who spends his days boiling sugar and fruit, have been well prepared to invent canning?
3. What would a modern food scientist want to measure that Appert could not?

> **Safety first.** A parent or responsible adult is at home and checks your oven work in this course, and your family checks every recipe against its own food allergies before you cook. Never taste raw batter (raw flour and raw eggs can carry germs). Use oven mitts and set the hot pan on a rack, not the counter edge.

KITCHEN LAB

The Scooping Lab and a Loaf Baked by Weight

Your first lab asks a simple question: *How much does a "cup" of flour really weigh?* You will measure it three ways, analyze the data like a scientist, and then bake banana bread with every ingredient weighed.

You will need

- A digital kitchen scale that reads grams
- A 1-cup dry measuring cup, a large spoon and a straight-edged knife
- Two mixing bowls, a whisk and a rubber spatula
- A 9 × 5-inch loaf pan and parchment or butter for greasing
- An instant-read thermometer
- Oven mitts and a cooling rack
- Your lab notebook and a calculator

Banana Bread by Weight

Serves 1 loaf (10–12 slices) · Prep 15 min · Bake 55–65 min · Cool 30 min

Ingredients

- 340 g very ripe bananas, peeled and mashed (about 3 medium, 1½ cups)
- 113 g (½ cup, 1 stick) butter, melted and slightly cooled
- 150 g (¾ cup packed) brown sugar
- 2 large eggs (about 100 g without shells)
- 1 teaspoon vanilla extract
- 250 g (about 2 cups) all-purpose flour
- 1 teaspoon (6 g) baking soda
- ½ teaspoon (3 g) salt
- Optional: 60 g (½ cup) chopped walnuts or chocolate chips

Method

1. Heat the oven to 350 °F (175 °C). Grease the loaf pan or line it with parchment.

2. Set a large bowl on the scale and press tare. Add the mashed bananas to 340 g. Tare again and add the melted butter, then the brown sugar, taring between each.
3. Crack the eggs into a small bowl first (to catch shells), then whisk them into the banana mixture with the vanilla.
4. Set the second bowl on the scale, tare, and weigh in the flour, baking soda and salt. Whisk them together.
5. Pour the dry ingredients into the wet ones and fold with the spatula just until no dry flour shows. Fold in nuts or chips if using. Do not taste the batter.
6. Scrape the batter into the pan. Bake 55–65 minutes, until a toothpick in the center comes out clean and the center of the loaf reads about 200–205 °F (93–96 °C).
7. Cool in the pan 10 minutes, then lift out onto a rack. Cool at least 20 minutes more before slicing.
8. Wash the bowls, scale platform and counter. Wrap leftovers and keep them up to 3 days at room temperature or freeze them.

Allergy check: Contains wheat, eggs and milk (butter); tree nuts if you add walnuts. For milk-free, use 100 g (½ cup) vegetable oil instead of butter. Chocolate chips often contain milk and soy.

Steps

1. **Question and prediction.** Write the question and your prediction: which method will give the heaviest cup, and by how much?
2. **Controlled variables.** Use the same bag of flour, the same measuring cup and the same scale for every trial. Tare the cup before each trial.
3. **Data.** Fill the cup five times by each method (dip and sweep; spoon and level; packed). Weigh each and record it in a table with units.
4. **Analysis.** For each method, find the mean and the range, and the percent error compared with 120 g.
5. **Bake.** Make the banana bread by weight. Record the oven temperature, the baking time and the center temperature of the loaf.
6. **Conclusion.** Write three or four sentences: answer the question, say whether your prediction was right, and explain why weighing gives more consistent

results.

7. **Improve it.** Calculate how many grams of flour your family's usual method would have put into this recipe, and predict how the loaf would have been different.
8. Clean up: wash, dry and put everything away; wipe flour from the counter with a damp cloth.

Tips

- Weigh sticky ingredients (bananas, honey, brown sugar) straight into the mixing bowl. No measuring cups to scrape.
- If your scale shuts off by itself, write each running total in your notebook as you go.
- Overripe bananas with plenty of brown spots are sweeter and mash more easily.

Check your work

- ☐ I can calculate a mean, a range and a percent error.
- ☐ I can explain why bakers measure flour by mass.
- ☐ I baked a loaf entirely by weight and recorded it as a lab.

LAB NOTEBOOK

1. Set up your lab notebook: a table of contents page, then this lab with question, prediction, data table (with units), calculations, conclusion and improvement.
2. Draw a cross-section of a dipped cup and a spooned cup of flour, showing how the particles pack differently.
3. Record the loaf: baking time, center temperature, a sketch of a slice, and a family rating from 1 to 5.

KEY FORMULAS

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

$$\text{range} = x_{\max} - x_{\min}$$

$$\text{percent error} = \frac{|\text{measured} - \text{accepted}|}{\text{accepted}} \times 100\%$$

From history. Appert opened one of the world's first canning factories at Massy, south of Paris. In England, Peter Durand patented the idea of using tin-plated iron cans in 1810, and by the 1820s canned foods were going on British naval voyages and polar expeditions.

WORKED EXAMPLES

Example 1. A student dips and sweeps one cup of flour five times and weighs each: 142, 138, 145, 140 and 135 g. Find the mean, the range and the percent error compared with 120 g.

Show solution

1. Mean: $\bar{x} = \dfrac{142 + 138 + 145 + 140 + 135}{5}\ \text{g} = \dfrac{700}{5}\ \text{g} = 140\ \text{g}$.
2. Range: $145\ \text{g} - 135\ \text{g} = 10\ \text{g}$.
3. Percent error: $\dfrac{|140 - 120|}{120} \times 100\% = 16.7\%$.

Answer: Mean 140 g, range 10 g, percent error about 17%. The dipped cups hold about one-sixth more flour than the recipe expects.

Example 2. A recipe calls for 2 cups of flour, meaning $2 \times 120\ \text{g} = 240\ \text{g}$. If you dip and sweep at 140 g per cup, how much extra flour goes into the bowl, and what percentage is that?

Show solution

1. Actual flour: $2 \times 140\ \text{g} = 280\ \text{g}$.
2. Extra: $280\ \text{g} - 240\ \text{g} = 40\ \text{g}$.
3. Percent extra: $\dfrac{40}{240} \times 100\% = 16.7\%$.

Answer: 40 g extra, about 17% more flour than intended: about a third of a cup.

Example 3. A stick of butter is labeled 113 g. Convert it to ounces ($1\text{ oz} = 28.35\text{ g}$), and find what fraction of a pound it is.

Show solution

1. $113\text{ g} \times \dfrac{1\text{ oz}}{28.35\text{ g}} = 3.99\text{ oz} \approx 4\text{ oz}$.
2. A pound is 16 oz, so $\dfrac{4\text{ oz}}{16\text{ oz}} = \dfrac{1}{4}$.

Answer: About 4 oz, one-quarter of a pound.

Example 4. Water has a density of about 1.00 g/mL, so 1 mL of water has a mass of 1 g. Milk is about 1.03 g/mL. Find the mass of 240 mL (1 cup) of each.

Show solution

1. Water: $m = \rho V = 1.00\ \frac{\text{g}}{\text{mL}} \times 240\text{ mL} = 240\text{ g}$.
2. Milk: $m = 1.03\ \frac{\text{g}}{\text{mL}} \times 240\text{ mL} = 247\text{ g}$.

Answer: Water 240 g; milk about 247 g. For liquids, a cup is a reliable measure; for flour it is not.

PRACTICE

1. Easy Name the two quantities a kitchen scale and a measuring cup measure.

   Show answer

   A scale measures mass (grams); a cup measures volume.

2. Easy Five weighings of spooned flour are 118, 122, 120, 117 and 123 g. Find the mean.

   Show answer

   $600/5 = 120\text{ g}$

3. Easy Find the range of the data in problem 2.

   Show answer

   $123 - 117 = 6\text{ g}$

4. **Medium** A packed cup of flour weighs 165 g. Find its percent error compared with 120 g.

   Show answer

   $45/120 \times 100\% = 37.5\%$

5. **Medium** Convert 1 lb of butter to grams (1 lb = 453.6 g). How many 113-g sticks is that?

   Show answer

   453.6 g; $453.6/113 \approx 4$ sticks.

6. **Medium** A recipe needs 3 cups of flour (360 g). Your family dips at 150 g a cup. How many grams too much flour is that?

   Show answer

   $3 \times 150 - 360 = 90$ g too much.

7. **Medium** When did Appert win the French government's prize, and what did he not yet understand about his method?

   Show answer

   1810. He did not know that microbes cause spoilage and that heat kills them; Pasteur explained that about fifty years later.

8. **Medium** Vegetable oil has a density of about 0.92 g/mL. Find the mass of ½ cup (120 mL).

   Show answer

   $0.92 \times 120 = 110$ g

9. **Hard** A student weighs 1 teaspoon of salt five times: 5.8, 6.1, 5.6, 6.0 and 5.5 g. Table salt is often listed at 6 g per teaspoon. Find the mean and the percent error. Is the scatter a bigger problem than the error?

   Show answer

   Mean $29.0/5 = 5.8$ g; percent error $0.2/6 \times 100\% = 3.3\%$. Range is 0.6 g, larger than the error, so the scatter (inconsistent leveling) matters more.

10. Hard Why might a kitchen scale that reads to the nearest 1 g be fine for flour but not for yeast or salt in a small batch?

Show answer

An error of 1 g is less than 1% of 250 g of flour but about 17–30% of 3–6 g of salt or yeast. Small amounts need a finer scale or careful spoon measures.

11. Challenge Design an experiment to find out whether sifting flour changes the mass of a cup. Name the independent, dependent and controlled variables and write a hypothesis.

Show answer

Independent: sifted or not sifted. Dependent: mass of one level cup. Controlled: same flour, cup, filling method (spoon and level), scale, number of trials. Hypothesis: sifted flour will weigh less per cup, because sifting adds air between particles.

COMMON MISTAKES

- Forgetting to tare. The bowl's mass gets counted as flour.
- Pressing the scale or leaning on the counter while it reads. Let it settle.
- Overmixing quick-bread batter. Fold just until combined, or the bread turns tough and tunneled.
- Tasting the batter. Raw flour and raw eggs can carry harmful bacteria.

Make it a game · Guess the Gram. Pick five pantry items. Weigh each in your hand and write a guess in grams. Then check on a scale and compute percent error for every guess. Add the five errors for your score; lower is better. Run the round twice, then try to beat your record. Finish by telling why Appert's jars worked before anyone knew why.

Scripture. "It is the glory of God to conceal a thing: but the honour of kings is to search out a matter." (Proverbs 25:2, KJV)

God has hidden wonderful order in the things we eat. Searching it out, patiently and honestly, is honorable work.

1.2 One Variable at a Time: The Cookie Experiment

OBJECTIVES

- Tell how Ruth Wakefield, a trained dietitian and cook, developed the chocolate chip cookie at the Toll House Inn in the 1930s.
- Design a fair test with one independent variable, a measured dependent variable and controlled variables.
- Halve a recipe with a yield factor and compare two cookie batches with means and a percent difference.

> **Warm-up.** Think of the best cookie you have ever eaten. Was it thin and crisp, or thick and chewy? Write down three things a baker could change to make a cookie spread more or less in the oven.

WATCH

How to make the perfect cookies (according to science) - Stephanie Warren

TED-Ed · 4:30

https://www.youtube.com/watch?v=n6wpNhyreDE

> **WHEN TO WATCH**
> During session 1, before you plan your experiment. Pause at each temperature on the screen and write down what is happening to the dough at that point.

BACKUP VIDEO

How to Cookie with Science

Reactions · 4:02

https://www.youtube.com/watch?v=3b4shT7EBZQ

Before the lab. A chemist tests chilled, room-temperature and melted butter, which is exactly your experiment; compare her results with yours afterward.

KEY TERMS

independent variable

The one thing you change on purpose in an experiment.

dependent variable

What you measure to see the effect of the change.

controlled variables

Everything you keep the same so that only the independent variable can cause a difference.

hypothesis

A testable prediction with a reason, often written "If ..., then ..., because ...."

yield factor

New yield divided by old yield; multiply every ingredient by it to scale a recipe.

spread

How much a cookie widens in the oven before it sets.

CORE IDEAS

The story. In 1930 Ruth Graves Wakefield and her husband Kenneth bought an old tollhouse in Whitman, Massachusetts, and opened the Toll House Inn. Ruth had trained in household arts and worked as a dietitian and food lecturer, and her restaurant became famous for its cooking and desserts. Sometime in the late 1930s she began adding chopped pieces of a semi-sweet chocolate bar to a butter cookie dough. Her "Toll House Chocolate Crunch Cookie" appeared in the 1938 edition of her cookbook, *Toll House Tried and True Recipes*, and its fame spread so quickly that the chocolate maker Nestlé began printing the recipe on its packages.

How they figured it out. A popular legend says the cookie was an accident, but Wakefield herself said she planned it, and her training suggests she would have tested it the way good cooks do: one change at a time, baked, tasted and adjusted. When a cookie spreads too much, a careful baker does not change the butter, the sugar and the oven all at once, because then no one can tell which change mattered. Change one thing, keep everything else the same, measure the result. That is a **fair test**.

The kitchen science. A cookie is a race in the oven. As the dough warms, the butter melts (around 90–95 °F, or 32–35 °C) and the dough begins to flow and spread. Water turns to steam and baking soda releases carbon dioxide, puffing the dough. Meanwhile the egg proteins and flour starches set, around 140–180 °F (60–82 °C), and that stops the spreading. Finally, above about 300 °F (150 °C) the surface browns through caramelization and the Maillard reaction. Anything that changes the timing of this race changes the cookie. Melted butter makes a looser dough that spreads sooner and farther, so the cookies come out thinner and chewier; cold or softened

butter holds tiny air bubbles from creaming and spreads more slowly, so the cookies are thicker.

Think it through. In this lab the **independent variable** is the state of the butter (softened or melted). The **dependent variables** are the diameter and thickness of each cookie. The **controlled variables** include the recipe, the mass of each dough ball, the pan, the oven temperature, the baking time and the position in the oven. Your hypothesis should predict a direction and give a reason.

Let's cook. You will make two half batches of a classic chocolate chip cookie, identical except for the butter. The skill is **portioning by mass**: weighing every ball of dough so each cookie starts the same.

PICTURE STUDY



The Baker Arent Oostwaard and His Wife Catharina Keizerswaard, Jan Steen, 1658 · Oil on panel · Rijksmuseum, Amsterdam

Image: Wikimedia Commons, public domain

Jan Steen painted a real baker of Leiden and his wife at their shop window, with the morning's baking set out for sale. In the Netherlands a baker blew a horn to announce that fresh bread was ready.

Look closely

- Count the different kinds of bread and pastry on the sill. Which look crisp and which look soft?
- Find the boy with the horn. Why would a baker need to announce when the bread came out?
- Look at the baker's bare forearms and white shirt. What does his clothing tell you about the heat of his work?
- Find pretzels and rolls that look alike. How would a baker keep every one the same size?

Talk about it

1. A baker who makes the same rolls every day is running a kind of experiment every morning. What would he notice if his oven ran hotter one day?
2. Why would weighing each piece of dough matter to a baker selling bread by the piece?

3. How is your cookie lab like this baker's daily work, and how is it different?

Safety first. Never taste raw cookie dough: raw flour and raw eggs can carry germs. Melt butter in short bursts in the microwave or over low heat and let it cool before adding eggs. Use oven mitts, and let cookies cool on the pan for 2 minutes before moving them.

KITCHEN LAB

The Butter Experiment

Does melting the butter change how much a cookie spreads? You will make two half batches, identical except for the butter, bake them side by side, and measure the results.

You will need

- A digital kitchen scale and measuring spoons
- Two mixing bowls, a whisk, a wooden spoon or stand mixer, and a rubber spatula
- Two identical baking sheets lined with parchment
- A ruler in centimeters
- Masking tape and a marker for labeling
- Oven mitts and a cooling rack
- Your lab notebook

Chocolate Chip Cookies (full batch; the lab makes two half batches)

Serves About 48 cookies · Prep 25 min · Bake 9–11 min per pan

Ingredients

- 280 g (2¼ cups) all-purpose flour
- 1 teaspoon baking soda
- 1 teaspoon salt
- 226 g (1 cup, 2 sticks) butter
- 150 g (¾ cup) granulated sugar
- 165 g (¾ cup packed) brown sugar
- 1 teaspoon vanilla extract
- 2 large eggs
- 340 g (2 cups) semi-sweet chocolate chips

Method

1. Heat the oven to 375 °F (190 °C) with a rack in the center.
2. Whisk the flour, baking soda and salt in a bowl.
3. In a second bowl, beat the butter and both sugars until light and fluffy, about 2 minutes (for melted butter, simply stir until smooth). Beat in the vanilla and eggs.
4. Stir in the flour mixture just until combined, then the chocolate chips. Do not taste the dough.
5. Scoop 30 g balls of dough, 2 inches apart, 12 to a pan.
6. Bake 9–11 minutes, until the edges are golden and the centers look just set. Cool 2 minutes on the pan, then move to a rack.
7. Wash everything with hot, soapy water, and wash your hands after handling raw dough.

Allergy check: Contains wheat, milk (butter) and eggs; most chocolate chips contain soy and may contain milk. For egg-free, use a commercial egg replacer and expect some change in spread. Check chip labels for nut cross-contact if needed.

Steps

1. **Hypothesis.** Write an "If ..., then ..., because ..." statement about melted versus softened butter.
2. **Variables.** List the independent variable, the dependent variables (diameter and thickness) and at least five controlled variables.
3. **Make batch A** (half recipe, butter softened at room temperature, creamed with the sugars). Label its bowl.
4. **Make batch B** (half recipe, butter melted and cooled to lukewarm, stirred with the sugars). Everything else identical.
5. **Portion.** Weigh twelve 30 g balls of each. Bake one pan of A and one pan of B, one at a time in the same position, for the same time.
6. **Measure.** When cool, measure the diameter and thickness of six cookies from each batch in centimeters. Record them in a table.
7. **Analyze.** Find the mean diameter and thickness for each batch, the spread ratios and the percent difference in diameter.
8. **Taste test.** Ask three family members to rate each batch from 1 to 5 for chewiness and for overall liking without telling them which is which.

9. **Conclusion.** Was your hypothesis supported? Explain the result with the melting-and-setting "race." Name one source of error.
10. Clean up: wash, dry and put away; wipe the counter.

Tips

- Bake both pans in the same oven position one after the other; two pans at once bake unevenly.
- Let a pan cool before you put the next dough on it. A warm pan starts the spreading early, which would be an uncontrolled variable.
- Freeze extra dough balls on a tray, then bag them, and bake them straight from the freezer for 1–2 minutes longer.

Check your work

- ☐ I can name independent, dependent and controlled variables.
- ☐ I can scale a recipe with a yield factor.
- ☐ I compared two batches with means and a percent difference and wrote a conclusion.

LAB NOTEBOOK

1. Draw the cookie "race" as a timeline from 70 °F to 350 °F, marking when butter melts, gas forms, proteins and starch set, and browning begins.
2. Write the lab report: hypothesis, variables, data table, calculations, conclusion and error.
3. Trace one cookie from each batch side by side, and add the family taste-test results.

KEY FORMULAS

$$\text{yield factor} = \frac{\text{new yield}}{\text{old yield}}$$

$$\text{spread ratio} = \frac{\text{diameter}}{\text{thickness}}$$

$$\text{percent difference} = \frac{|A - B|}{(A + B)/2} \times 100\%$$

From history. Ruth Wakefield gave Nestlé the right to print her recipe on its packages; the story is often told that she was paid with a lifetime supply of chocolate. Her inn burned in 1984, but the recipe printed on bags of chocolate chips is still close to hers.

WORKED EXAMPLES

Example 1. The full recipe uses 280 g flour, 226 g butter, 150 g granulated sugar, 165 g brown sugar and 340 g chocolate chips and makes about 48 cookies. Find the amounts for a half batch.

Show solution

1. Yield factor: $\dfrac{24}{48} = 0.5$.
2. Flour $280 \times 0.5 = 140$ g; butter $226 \times 0.5 = 113$ g; granulated sugar 75 g; brown sugar 82.5 g; chips 170 g.
3. The 2 eggs become 1 egg, and each teaspoon of soda, salt and vanilla becomes ½ teaspoon.

Answer: 140 g flour, 113 g butter, 75 g white sugar, about 83 g brown sugar, 170 g chips, 1 egg, ½ tsp each soda, salt and vanilla.

Example 2. Six softened-butter cookies measure 7.2, 7.5, 7.0, 7.4, 7.3 and 7.2 cm across. Six melted-butter cookies measure 8.6, 8.9, 8.4, 8.8, 8.7 and 8.6 cm. Find each mean and the percent difference.

Show solution

1. Softened: $\bar{d} = \dfrac{43.6}{6}\ \text{cm} = 7.27\ \text{cm}$.
2. Melted: $\bar{d} = \dfrac{52.0}{6}\ \text{cm} = 8.67\ \text{cm}$.
3. Percent difference: $\dfrac{|8.67 - 7.27|}{(8.67 + 7.27)/2} \times 100\% = \dfrac{1.40}{7.97} \times 100\% = 17.6\%$.

Answer: Means 7.27 cm and 8.67 cm; the melted-butter cookies spread about 18% more. The ranges (0.5 cm each) are much smaller than the difference, so the effect is real.

Example 3. A softened-butter cookie is 7.3 cm wide and 1.4 cm thick; a melted-butter cookie is 8.7 cm wide and 0.9 cm thick. Find each spread ratio.

Show solution

1. Softened: $\dfrac{7.3\text{ cm}}{1.4\text{ cm}} = 5.2$.
2. Melted: $\dfrac{8.7\text{ cm}}{0.9\text{ cm}} = 9.7$.

Answer: 5.2 and 9.7. A higher spread ratio means a flatter cookie; the units cancel, so the ratio has no unit.

PRACTICE

1. Easy In an experiment on how oven temperature affects cookie color, name the independent and dependent variables.

   Show answer

   Independent: oven temperature. Dependent: cookie color (or browning).

2. Easy Find the yield factor to turn a 48-cookie recipe into 12 cookies.

   Show answer

   $12/48 = 0.25$

3. Easy Using the yield factor from problem 2, how much flour does 280 g become?

   Show answer

   $280 \times 0.25 = 70$ g

4. Medium Find the yield factor to make 72 cookies from the 48-cookie recipe, and the amount of chocolate chips.

   Show answer

   $72/48 = 1.5$; $340 \times 1.5 = 510$ g

5. Medium Batch A's mean thickness is 1.42 cm and batch B's is 0.95 cm. Find the percent difference.

   Show answer

   $0.47/1.185 \times 100\% = 39.7\%$

6. Medium A student changed both the butter and the baking time between batches. What is wrong with the experiment?

Show answer

Two variables changed, so any difference cannot be blamed on either one; it is not a fair test.

7. Medium Why does a cookie stop spreading?

Show answer

Egg proteins and flour starch set as the dough heats (around 140–180 °F), firming the structure.

8. Medium In what cookbook and year did Ruth Wakefield's chocolate chip cookie appear?

Show answer

Toll House Tried and True Recipes, 1938 edition.

9. Hard Predict what will happen to spread if the dough balls are chilled for an hour before baking, and explain.

Show answer

Less spread. The cold butter takes longer to melt, so the proteins and starch have more time to set before the dough flows.

10. Hard Batch A diameters range from 7.0 to 7.5 cm and batch B from 7.2 to 7.7 cm. Can you conclude the treatments differ? Explain.

Show answer

Not confidently. The ranges overlap almost completely and the means differ by only about 0.2 cm, smaller than the scatter. More trials are needed.

11. Challenge A full batch makes 48 cookies at 30 g each. Estimate the total dough mass from the ingredients (280 g flour, 226 g butter, 150 g and 165 g sugars, 100 g eggs, 340 g chips, about 15 g soda, salt and vanilla), and compare with 48 × 30 g. Explain the difference.

Show answer

Ingredients ≈ 1276 g; 48 × 30 g = 1440 g. The recipe makes only about 42 cookies of 30 g; the "48" assumes smaller cookies (about 27 g). Recipe yields are estimates; weigh to know.

COMMON MISTAKES

- Changing two things at once (for example, melted butter and a hotter oven).
- Eyeballing dough portions. A bigger ball spreads more, which hides the effect you are testing.
- Putting dough on a hot pan from the last batch.
- Tasting raw dough “just a little.”

> **Make it a game · Fair Test Referee.** Your parent describes a flawed cookie experiment: new butter, a different oven temperature and a longer bake all at once. Name the independent, dependent and controlled variables, then rewrite the test so only one thing changes. Run four flawed experiments. Say what Ruth Wakefield tested differently from a casual baker.

1.3 Safe Lab Practice: Knives, Heat, Fire and Sanitizer

OBJECTIVES

- Explain the fire triangle and why a grease fire must be smothered with a lid or baking soda, never water; tell how George Manby's 1818 extinguisher worked.
- Use a chef's knife safely with the claw and bridge grips, and show why uniform cuts cook evenly.
- Mix a correct bleach sanitizer and calculate its concentration in parts per million (ppm).

> **Warm-up.** Walk through your kitchen with your notebook. Where is the fire extinguisher, if there is one? Where are the pot lids? Where does the knife live? Sketch a map and mark anything that would be unsafe to have near the stove.

WATCH

VCFD Kitchen Fire Safety

Ventura County Fire Department · 4:45

https://www.youtube.com/watch?v=rgr7UOYn1S8

> **WHEN TO WATCH**
> During session 1. Make a list of every kitchen-fire rule the firefighters give, and mark the three you think matter most.

BACKUP VIDEO

Wrong vs. right way to put out a grease fire | Ohio State Medical Center

Ohio State Wexner Medical Center · 2:09

https://www.youtube.com/watch?v=6E2d-bVKfNk

After the main video. Watch what happens when a cup of water hits burning oil, so that you never try it yourself.

KEY TERMS

fire triangle

The three things every fire needs: fuel, heat and oxygen. Remove any one and the fire goes out.

grease fire

A fire in cooking oil or fat. Water sinks under the burning oil, flashes to steam and throws flaming oil into the air.

claw grip

Holding food with fingertips curled under and knuckles forward, so the blade rests against the knuckles, not the fingertips.

bridge grip

Holding food with thumb and fingers on either side, forming an arch the knife passes under.

sanitize

To reduce germs on a clean surface to a safe level, for example with a measured bleach solution. Cleaning (soap and water) comes first.

ppm (parts per million)

A unit of concentration: 1 ppm is 1 part of a substance in 1,000,000 parts of the mixture.

CORE IDEAS

The story. In 1813 George William Manby, an English barracks-master, watched firemen fail to reach a blaze on the upper floor of a building in Edinburgh. He spent the next years designing a portable fire extinguisher, and in 1818 he demonstrated it: a copper vessel holding about 3 gallons of a potassium carbonate (pearl ash) solution, with compressed air above it to drive the liquid out through a nozzle. It was the ancestor of the red cylinder that should hang near your kitchen today. Fire departments in the United States still report that cooking is the leading cause of home fires and home fire injuries, most often when cooking is left unattended.

How they figured it out. Manby's idea was to bring the right extinguishing material to the fire quickly, before it grew. The science behind it is the **fire triangle**: fuel, heat and oxygen. Water works on wood fires because it cools them below their ignition temperature. But firefighters learned through hard experience that water is the wrong tool for burning fat. Oil floats on water; water is denser, sinks to the bottom of the pan, and flashes instantly to steam, expanding more than a thousand times and blasting the burning oil upward as a fireball.

The kitchen science. For a grease fire, break the triangle safely: turn off the heat (remove heat), slide a lid or baking sheet over the pan and leave it there (remove oxygen), and do not carry the pan. Baking soda smothers a small fire and releases carbon dioxide; flour does not (it can burn). If a fire is bigger than a lid can cover, get everyone out and call 911. A **sharp knife** is safer than a dull one because it bites into food instead of slipping. Uniform pieces matter for science and safety alike: pieces of the same size cook at the same rate, so you are not left with some pieces raw and others burnt. Finally, clean and sanitize. Soap and water remove grease and food; then a sanitizer of about 1 tablespoon of unscented household bleach in 1 gallon of water (the USDA's recipe) reduces germs on cutting boards and counters. Never mix bleach with ammonia or vinegar: both release toxic gases.

Let's cook. You will cook a chicken and vegetable stir-fry, which brings the whole lesson together: knife work, separate boards for raw chicken and vegetables, a very hot pan with a thin film of oil, a lid within reach, and chicken cooked to 165 °F.

PICTURE STUDY



Interior of a Kitchen, Martin Drolling, 1815 · Oil on canvas · Musée du Louvre, Paris

Image: Wikimedia Commons, public domain

Drolling painted a quiet French kitchen around the time Manby was designing his extinguisher. Cooking was done over an open hearth, and every household lived with fire every day.

Look closely

- Find the hearth. Where is the fire, and what is near it?
- Find the pots and pans. Which ones are metal and which are clay? Which would get hot fastest?
- Find the child. How close is the child to the fire? What rule would you make for this kitchen?
- Find the window. Why would a kitchen with an open fire need good light and good air?

Talk about it

1. Using the fire triangle, explain how a cook in this kitchen would put out a small fire in a pan of fat.
2. Modern stoves hide the flame or have none. Does that make kitchens completely safe? What dangers are left?

3. Make a list of three safety habits you would teach a younger child entering this kitchen.

Safety first. Never use water on a grease fire: turn off the heat and cover the pan with a lid; if the fire grows, get out and call 911. Practice knife grips with a parent watching before you work alone, keep a damp towel under the board, and never try to catch a falling knife. Bleach is for surfaces only: wear gloves, never mix it with ammonia, vinegar or other cleaners, and keep it away from food.

KITCHEN LAB

The Safe-Kitchen Lab and a Stir-Fry

This lab has three stations: a kitchen safety audit, a knife-uniformity test, and the sanitizer calculation, followed by a stir-fry that uses all three.

You will need

- A chef's knife, a paring knife and two cutting boards (one for raw chicken)
- A damp towel under each board
- A digital kitchen scale and a ruler
- A large skillet or wok with a lid that fits
- A box of baking soda by the stove
- A 1-gallon container, a tablespoon, rubber gloves and unscented household bleach
- An instant-read thermometer
- Your lab notebook

Chicken and Vegetable Stir-Fry

Serves 4–5 · Prep 30 min · Cook 12 min

Ingredients

- 1 lb (450 g) boneless, skinless chicken breasts or thighs, sliced ¼ inch thick
- 1 tablespoon soy sauce and 1 tablespoon cornstarch (for the chicken)
- 2 tablespoons vegetable oil, divided
- 3 cups (about 250 g) broccoli florets
- 2 carrots, peeled and cut into thin coins
- 1 red bell pepper, cut into 1-inch squares
- 3 cloves garlic, minced, and 1 tablespoon grated fresh ginger
- Sauce: ½ cup chicken broth, 2 tablespoons soy sauce, 1 tablespoon honey, 1 tablespoon rice vinegar, 2 teaspoons cornstarch
- Cooked rice for serving (1½ cups uncooked rice makes about 4½ cups)

Method

1. Start the rice. Whisk the sauce ingredients in a small bowl.
2. On the raw-meat board, slice the chicken. Toss it with 1 tablespoon soy sauce and 1 tablespoon cornstarch. Wash the knife and your hands with hot soapy water before touching anything else.
3. On the vegetable board, cut the vegetables, aiming for pieces of the same size. Set everything by the stove with the lid and baking soda in reach.
4. Heat 1 tablespoon oil in the skillet over medium-high heat until it shimmers (not smokes). Add the chicken in one layer and cook 2 minutes without stirring, then stir-fry 2–3 minutes more until it reaches 165 °F (74 °C) in the thickest piece. Move it to a clean plate.
5. Add the remaining oil, the carrots and broccoli; stir-fry 2 minutes. Add 2 tablespoons water and cover for 1 minute to steam. Add the pepper, garlic and ginger and stir 1 minute.
6. Stir the sauce and pour it in; stir until thick and glossy, about 1 minute. Return the chicken and toss. Serve over rice.
7. Refrigerate leftovers within 2 hours. Clean both boards and the counter with soap and water, then sanitize them with the bleach solution and let them air-dry.

Allergy check: Contains soy and wheat (soy sauce). For wheat-free, use tamari labeled gluten-free. Honey is never given to babies under one year. Check your broth label for allergens.

Steps

1. **Safety audit.** With a parent, check: smoke alarm working, fire extinguisher location and gauge, lids for every pan, baking soda near the stove, pot handles turned in, towels and paper away from burners. Record each item as pass or fix.
2. **Grip practice.** With a parent watching, practice the claw grip slicing a carrot and the bridge grip halving a bell pepper. Have your parent initial your notebook when both are safe.
3. **Uniformity test.** Cut a carrot into coins about ¼ inch thick. Weigh 10 coins, find the mean and range. Cut 10 more, aiming to beat your range, and weigh

again.

4. **Sanitizer.** Wearing gloves, mix 1 tablespoon unscented bleach into 1 gallon of cool water. Read the bleach percentage on the label and calculate the ppm.
5. **Cook.** Make the stir-fry, checking the chicken with the thermometer and recording its temperature.
6. **Cleanup as a lab step.** Wash, rinse and sanitize the boards and counter. Record the order you used and why soap comes before sanitizer.
7. **Conclusion.** Did your second set of carrot coins have a smaller range? Did the vegetables cook evenly? Write two improvements.

Tips

- Partly freeze chicken for 20 minutes to make thin slices easier and safer.
- Hold the chef's knife with a "pinch grip": thumb and forefinger pinching the blade just ahead of the handle.
- Make sanitizer fresh each day; it weakens over time.

Check your work

☐ I can explain the fire triangle and what to do for a grease fire.

☐ I used the claw and bridge grips safely and measured my cutting uniformity.

☐ I mixed a sanitizer correctly and calculated its concentration.

LAB NOTEBOOK

1. Draw the fire triangle and show how a lid, turning off the burner, and baking soda each break it.
2. Draw the claw and bridge grips from above, labeling where the blade touches.
3. Record the safety audit, the uniformity data and your sanitizer calculation.

KEY FORMULAS

$$\text{ppm} = \frac{\text{amount of solute}}{\text{amount of solution}} \times 10^6$$

$$C = \tfrac{5}{9}(F - 32)$$

From history. Manby is also remembered for the "Manby mortar," which fired a line from shore to a stranded ship so sailors could be pulled to safety; it is credited with saving many lives along the English coast. The modern Class K extinguisher, made for commercial kitchens, sprays a solution that reacts with hot fat to form a soapy crust that smothers the fire.

WORKED EXAMPLES

Example 1. Household bleach is about 6% sodium hypochlorite. You add 1 tablespoon (15 mL) to 1 gallon (3,785 mL) of water. Estimate the concentration of sodium hypochlorite in ppm.

Show solution

1. Sodium hypochlorite in 15 mL of bleach: $0.06 \times 15\ \text{mL} = 0.90\ \text{mL}$.
2. Total volume: $3785\ \text{mL} + 15\ \text{mL} = 3800\ \text{mL}$.
3. Concentration: $\dfrac{0.90\ \text{mL}}{3800\ \text{mL}} \times 10^{6} = 237\ \text{ppm}$.

Answer: About 240 ppm, close to the 200 ppm range food-safety agencies recommend for sanitizing food-contact surfaces.

Example 2. A newer bleach is 8.25% sodium hypochlorite. How many milliliters in 1 gallon gives the same 237 ppm?

Show solution

1. Needed hypochlorite: $237 \times 10^{-6} \times 3800\ \text{mL} = 0.90\ \text{mL}$.
2. Bleach needed: $\dfrac{0.90\ \text{mL}}{0.0825} = 10.9\ \text{mL}$.

Answer: About 11 mL, roughly 2 teaspoons. Always read the label: stronger bleach needs less.

Example 3. Vegetable oil begins to smoke at about 400 °F and can ignite (flash point) near 600 °F. Convert both to Celsius.

Show solution

1. $C = \frac{5}{9}(400 - 32) = \frac{5}{9}(368) = 204\ ^\circ\text{C}$.
2. $C = \frac{5}{9}(600 - 32) = \frac{5}{9}(568) = 316\ ^\circ\text{C}$.

Answer: About 204 °C and 316 °C. Smoke is your warning: turn the heat down long before the oil can catch fire.

Example 4. You cut 10 carrot pieces for a stir-fry and weigh them: 8, 9, 8, 12, 7, 8, 15, 8, 9, 6 g. Find the mean and range. What does the range tell you about how evenly they will cook?

Show solution

1. Mean: $\frac{90}{10}\ \text{g} = 9.0\ \text{g}$.
2. Range: $15\ \text{g} - 6\ \text{g} = 9\ \text{g}$, as large as the mean itself.

Answer: Mean 9.0 g, range 9 g. The largest piece is more than twice the smallest, so it will still be crunchy when the small ones are soft. Practice until the range is a few grams.

PRACTICE

1. Easy Name the three sides of the fire triangle.

   Show answer

   Fuel, heat and oxygen.

2. Easy What two things should you do first if oil catches fire in a pan?

   Show answer

   Turn off the heat and cover the pan with a lid (or baking sheet); leave it covered.

3. Easy Why is a sharp knife safer than a dull one?

   Show answer

   It cuts with less force, so it is less likely to slip off the food into your hand.

4. **Medium** Explain why water makes a grease fire worse.

   Show answer

   Water is denser than oil, sinks under it and flashes to steam, expanding greatly and throwing burning oil into the air.

5. **Medium** Convert a 350 °F oven to Celsius.

   Show answer

   $\frac{5}{9}(350 - 32) = 177\ ^\circ\text{C}$

6. **Medium** What did George Manby's 1818 extinguisher contain?

   Show answer

   About 3 gallons of potassium carbonate (pearl ash) solution in a copper vessel, driven out by compressed air.

7. **Medium** Why must you clean with soap and water before using sanitizer?

   Show answer

   Food and grease shield germs and use up the sanitizer; cleaning removes them so the sanitizer can reach the surface.

8. **Medium** Find the ppm of a solution with 2 g of salt in 1,000 g of water.

   Show answer

   $2/1002 \times 10^6 \approx 2000$ ppm

9. **Hard** A sanitizer test strip should read 50–200 ppm for some uses. Your solution made with 6% bleach at 1 tbsp per gallon is about 240 ppm. How much more water would bring it to 200 ppm?

   Show answer

   Concentration × volume stays constant: $240 \times 3.8 = 200 \times V$, so $V = 4.56$ L; add about 0.76 L (about 3 cups) of water.

10. **Hard** Ten carrot pieces have a mean of 10 g and a range of 2 g; another ten have a mean of 10 g and a range of 9 g. Which set is better for a stir-fry and why?

    Show answer

    The first: the small range means the pieces are nearly the same size and will be done at the same time.

11. **Challenge** Why does baking soda help put out a small grease fire, but flour does not? Use chemistry.

    Show answer

    Heat decomposes sodium bicarbonate: $2\,NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$; the CO_2 and the powder blanket the fire and shut out oxygen. Flour is a fuel (starch) whose fine dust can burn rapidly.

COMMON MISTAKES

- Walking away from a hot pan. Unattended cooking is the leading cause of kitchen fires.
- Carrying a burning pan to the sink or outdoors. Cover it and turn off the heat instead.
- Mixing bleach with vinegar or ammonia “to make it stronger.” It makes toxic gas.
- Using the same board for raw chicken and vegetables without washing and sanitizing it.

> **Make it a game · Safety Callout.** Your parent reads emergency scenarios: oil smoking in a pan, a knife sliding off a round vegetable, wet hands near the stove, sanitizer too weak. For each, say the correct response in five seconds, using the fire triangle, claw grip and parts per million. Never use real flame. Name what George Manby's 1818 extinguisher did.

1.4 Fahrenheit, Celsius and the Calibrated Thermometer

OBJECTIVES

- Tell how Daniel Gabriel Fahrenheit (1724) and Anders Celsius (1742) built temperature scales on fixed points.
- Convert between °F and °C, and calibrate a thermometer with ice water and boiling water, correcting for altitude.
- Roast chicken thighs and log their temperature over time to the USDA safe minimum of 165 °F.

> **Warm-up.** Fill a glass with ice and a little water and wait 3 minutes. Stick your thermometer in it. What does it read? What should it read? Write both numbers down, and guess why they might differ.

WATCH

Fahrenheit to Celsius: History of the thermometer

Met Office - Learn About Weather · 8:06

https://www.youtube.com/watch?v=rARnTlPax8E

> **WHEN TO WATCH**
> During session 1. Take notes on each scale's fixed points: what Fahrenheit and Celsius used for 0 and for their upper point.

BACKUP VIDEO

A Flash of Food Safety Calibrating a Thermometer: Ice Water Method

USDA · 2:54

https://www.youtube.com/watch?v=KCjb85pZb6c

Right before you calibrate. Follow the ice-water method exactly as shown.

KEY TERMS

fixed point

A temperature that can be reproduced anywhere, such as melting ice or boiling water, used to mark a thermometer scale.

calibrate

To check an instrument against known values and correct it.

Celsius scale

The temperature scale with water freezing at 0 °C and boiling at 100 °C at sea-level pressure.

Fahrenheit scale

The temperature scale with water freezing at 32 °F and boiling at 212 °F at sea-level pressure.

safe minimum internal temperature

The USDA temperature that a food's thickest part must reach to make it safe: 165 °F for poultry.

carryover cooking

The rise in a food's internal temperature after it leaves the heat, as heat moves inward from the hot outside.

CORE IDEAS

The story. Daniel Gabriel Fahrenheit was born in Danzig (now Gdańsk) in 1686 and became an instrument maker in the Netherlands. He made the first reliable mercury thermometers around 1714, and in 1724 he described his temperature scale to the Royal Society in London. Fahrenheit set 0 at the coldest temperature he could make with a mixture of ice, water and a salt, and used the freezing of water and the human body as other reference points; on his finished scale water freezes at 32° and boils at 212°. In 1742 the Swedish astronomer Anders Celsius proposed a scale with 100 steps between the freezing and boiling points of water. Celsius actually put 100 at freezing and 0 at boiling; soon after his death in 1744 the scale was turned over into the form we use.

How they figured it out. The great problem was agreement. Early thermometers each had their own marks, so a reading in one city meant nothing in another. Fahrenheit's mercury thermometers matched each other, because he built them carefully and marked them from reproducible fixed points. Celsius showed carefully that melting snow always gives the same reading, but that the boiling point depends on air pressure, so it must be measured at a standard pressure.

The kitchen science. Your thermometer is only as good as its calibration. In a slurry of ice and water, stirred, it should read 32 °F (0 °C). In boiling water at sea level it should read 212 °F (100 °C), but water boils at a lower temperature at higher altitude, about 1 °F lower for every 500 feet. Many digital thermometers can be reset; dial thermometers have a nut you turn. For conversion, each Celsius degree is 1.8 (that is, 9/5) Fahrenheit degrees, and the scales are offset by 32. Temperature is the key number in food safety: the USDA's safe minimum internal temperatures are 165 °F (74 °C) for poultry, 160 °F (71 °C) for ground beef, pork and egg dishes, and 145 °F (63 °C) for whole cuts of beef, pork, veal and lamb (with a 3-minute rest) and for fish. Measure in the thickest part, not touching bone.

Let's cook. You will roast chicken thighs and take their temperature every 5 minutes near the end, plotting a heating curve. Thighs are safe at 165 °F, but because they contain more connective tissue than breast meat, many cooks take them to 175–185 °F for tenderness. The skill is **reading a thermometer correctly**: in the thickest part, from the side, away from bone.

PICTURE STUDY



Portrait of Anders Celsius, Olof Arenius, Before 1744 · Oil on canvas · Uppsala University, Sweden

Image: Wikimedia Commons, public domain

Anders Celsius (1701–1744) was a professor of astronomy at Uppsala. His careful experiments with melting snow and boiling water gave the world the 100-step scale used by scientists everywhere.

Look closely

- Look at his face and expression. What kind of patience would a man need to repeat the same measurement hundreds of times?
- Look at his clothing and wig. About when do you think this was painted?
- Imagine the instruments in his observatory. What would he need to measure besides temperature?

Talk about it

1. Celsius found that the boiling point changes with air pressure. Why does that matter to a cook in the mountains?
2. Why do you think scientists prefer the Celsius scale, while American cooks still use Fahrenheit?
3. What fixed points could you use in your kitchen to check a thermometer?

> **Safety first.** Boiling water and steam burn: use a deep pot, keep the thermometer stem in the water rather than your hand over the steam, and let the pot cool before moving it. Wash the thermometer stem with hot soapy water after each time it touches raw chicken. Chicken must reach 165 °F (74 °C) in the thickest part.

KITCHEN LAB

Calibrate, Then Cook to a Number

First you will calibrate your thermometer and calculate your local boiling point. Then you will roast chicken thighs, log their temperature over time and graph the heating curve.

You will need

- An instant-read thermometer (and a dial thermometer if you have one)
- A tall glass, ice and water
- A small pot of water
- A rimmed baking sheet lined with foil and a wire rack if you have one
- Tongs, oven mitts and a cutting board for raw meat
- Graph paper or a spreadsheet
- Your lab notebook

Lemon-Garlic Roasted Chicken Thighs

Serves 4–6 · Prep 10 min · Roast 35–45 min

Ingredients

- 8 bone-in, skin-on chicken thighs (about 3 lb, 1.4 kg)
- 2 tablespoons olive oil
- 1½ teaspoons salt and ½ teaspoon black pepper
- 4 cloves garlic, minced
- 1 lemon: zest and 2 tablespoons juice
- 1 teaspoon dried thyme or oregano
- ½ teaspoon paprika

Method

1. Heat the oven to 425 °F (220 °C). Line the sheet with foil and set a rack on it if you have one.
2. Pat the thighs dry with paper towels (do not rinse raw chicken). Throw the towels away and wash your hands.

3. In a large bowl, mix the oil, salt, pepper, garlic, lemon zest and juice, thyme and paprika. Add the thighs and turn to coat. Arrange them skin side up, not touching.
4. Roast 25 minutes, then begin checking the thickest thigh every 5 minutes. Remove when it reads at least 165 °F (74 °C); for the most tender meat, 175–185 °F. Total time is usually 35–45 minutes.
5. Rest 5 minutes, then serve. Refrigerate leftovers within 2 hours and reheat to 165 °F.
6. Soak the pan, wash the bowl, tongs and board with hot soapy water, and wipe the counter.

Allergy check: Contains none of the nine major allergens. Check your spice blends for added ingredients.

Steps

1. **Ice point.** Pack a tall glass with ice, add cold water to the top, stir, and wait 3 minutes. Insert the thermometer at least 2 inches without touching the glass. Record the reading.
2. **Boiling point.** Look up your town's altitude and calculate the expected boiling point. Bring water to a full rolling boil and record the reading (stem in the water, not touching the pot).
3. **Correct.** Adjust the thermometer if it allows it, or write a correction formula like Worked Example 3.
4. **Cook and log.** Roast the chicken. Starting at 25 minutes, record the temperature of the same thigh every 5 minutes (corrected for calibration).
5. **Carryover.** After removing the pan, record the temperature at 0, 2 and 5 minutes of resting.
6. **Graph.** Plot temperature against time. Draw a horizontal line at 165 °F.
7. **Conclusion.** How far off was your thermometer? Did the temperature rise steadily? How much carryover did you see?
8. Clean up and sanitize everything that touched raw chicken.

Tips

- Insert the probe from the side into the thickest part of the thigh, so the tip sits in the center of the meat.

- A thin-tipped digital thermometer reads in about 3 seconds; a dial thermometer needs 15–20 seconds and a deeper insertion.
- Write the calibration date on a strip of tape on your thermometer's case.

Check your work

- ☐ I can convert between °F and °C and predict my local boiling point.
- ☐ I calibrated my thermometer at two fixed points.
- ☐ I cooked chicken to a measured safe temperature and graphed the heating curve.

LAB NOTEBOOK

1. Draw a thermometer with the Fahrenheit and Celsius scales side by side, marking 0 °F, 32 °F, 145 °F, 160 °F, 165 °F and 212 °F with their Celsius values.
2. Record your calibration data and your correction formula.
3. Paste or draw your heating-curve graph with labeled axes and units.

KEY FORMULAS

$$C = \tfrac{5}{9}(F - 32) \qquad F = \tfrac{9}{5}C + 32$$

$$T_{\text{boil}} \approx 212\ ^\circ\text{F} - \frac{\text{altitude (ft)}}{500\ \text{ft}} \times 1\ ^\circ\text{F}$$

From history. Galileo built a thermoscope around 1593 that showed hotter and colder but had no scale. The Florentine Accademia del Cimento made sealed liquid-in-glass thermometers in the 1650s. The kelvin, the scientific unit of temperature, uses Celsius-sized degrees but starts at absolute zero, −273.15 °C.

WORKED EXAMPLES

Example 1. Convert the poultry safe temperature, 165 °F, to Celsius, and the 145 °F fish temperature to Celsius.

Show solution

1. $C = \tfrac{5}{9}(165 - 32) = \tfrac{5}{9}(133) = 73.9\ ^\circ\text{C}$, usually rounded to 74 °C.
2. $C = \tfrac{5}{9}(145 - 32) = \tfrac{5}{9}(113) = 62.8\ ^\circ\text{C}$, usually given as 63 °C.

Answer: 74 °C and 63 °C.

Example 2. You live at 4,500 ft. At what temperature should your thermometer read in boiling water?

Show solution

1. Drop: $\dfrac{4500\ \text{ft}}{500\ \text{ft}} \times 1\ ^\circ\text{F} = 9\ ^\circ\text{F}$.
2. Boiling point: $212\ ^\circ\text{F} - 9\ ^\circ\text{F} = 203\ ^\circ\text{F}$.
3. In Celsius: $\frac{5}{9}(203 - 32) = 95\ ^\circ\text{C}$.

Answer: About 203 °F (95 °C). The 500-ft rule is an approximation; weather also changes air pressure by a degree or so.

Example 3. A thermometer reads 34 °F in ice water and 210 °F in boiling water at sea level. Find a correction formula, and correct a reading of 160 °F.

Show solution

1. The true span is $212 - 32 = 180\ ^\circ\text{F}$; the thermometer's span is $210 - 34 = 176\ ^\circ\text{F}$.
2. True temperature: $T = 32 + \dfrac{180}{176}(R - 34)$, where R is the reading.
3. For $R = 160$: $T = 32 + 1.023(126) = 32 + 128.9 = 160.9\ ^\circ\text{F}$.

Answer: About 161 °F. This thermometer is close near cooking temperatures, but it is 2 °F off at the ends; a simple one-point fix at 32 °F would make it read 2 °F low in the cooking range.

Example 4. A chicken thigh reads 128 °F at 20 minutes and 158 °F at 30 minutes. Assuming a steady rate, estimate when it reaches 165 °F.

Show solution

1. Rate: $\dfrac{158 - 128}{30 - 20}\ \frac{^\circ\text{F}}{\text{min}} = 3.0\ \frac{^\circ\text{F}}{\text{min}}$.
2. Remaining: $\dfrac{165 - 158}{3.0}\ \text{min} = 2.3\ \text{min}$.

Answer: About 32–33 minutes. In reality the rate slows near the end, so check again rather than trusting the estimate.

PRACTICE

1. Easy Convert 100 °C to °F.

   Show answer

   $\frac{9}{5}(100) + 32 = 212\ ^\circ\text{F}$

2. Easy Convert 40 °F (the refrigerator limit) to °C.

   Show answer

   $\frac{5}{9}(8) = 4.4\ ^\circ\text{C}$

3. Easy What is the USDA safe minimum internal temperature for ground beef?

   Show answer

   160 °F (71 °C).

4. Medium Convert 350 °F and 425 °F to °C.

   Show answer

   177 °C and 218 °C.

5. Medium At what temperature are the Fahrenheit and Celsius readings equal? Show your work.

   Show answer

   Set $F = C = x$: $x = \frac{9}{5}x + 32 \Rightarrow -\frac{4}{5}x = 32 \Rightarrow x = -40$. At −40°.

6. Medium Estimate the boiling point of water in Denver (5,280 ft).

   Show answer

   $212 - 5280/500 = 212 - 10.6 \approx 201\ ^\circ\text{F}$

7. Medium In what year did Fahrenheit publish his scale, and in what year did Celsius propose his?

   Show answer

   1724 and 1742.

8. Medium A thermometer reads 30 °F in ice water. If its error is the same at all temperatures, what is the true temperature when it reads 163 °F? Is the chicken safe?

   Show answer

   $163 + 2 = 165\ ^\circ\text{F}$; just safe, but check again.

9. Hard A temperature difference of 10 °C is how many °F? Why is this not the same as converting 10 °C?

Show answer

A difference converts by the factor only: $10 \times 1.8 = 18$ °F. Converting the temperature 10 °C gives 50 °F because it also adds the 32° offset.

10. Hard Why must the thermometer probe not touch bone or the pan?

Show answer

Bone and metal conduct heat differently and can be hotter than the meat, giving a falsely high reading.

11. Challenge A chicken thigh's temperature rises 3 °F per minute at 150 °F but only 1 °F per minute at 170 °F. Suggest a physical reason.

Show answer

As the meat's inside approaches the oven-heated outside, the temperature difference driving heat inward shrinks; also water evaporating from the surface takes energy. Heating slows as the gap closes.

COMMON MISTAKES

- Measuring the thinnest piece, or reading too quickly before the number settles.
- Assuming water boils at 212 °F everywhere.
- Converting a temperature difference by adding 32.
- Using a thermometer on cooked food after it touched raw chicken without washing it.

> **Make it a game · Convert and Calibrate.** Your parent calls temperatures in Fahrenheit or Celsius: 32, 212, 165, 100, 74. Convert each in your head or on paper with the formula, racing the clock. Then state the two fixed points used to calibrate a thermometer and what a reading of 34 in ice water would mean. Record your best round of ten.

1.5 James Lind's Fair Test and the Popcorn Experiment

OBJECTIVES

- Tell how James Lind ran a controlled comparison of six scurvy treatments aboard HMS *Salisbury* in 1747, and read a short scientific report for its question, method, results and conclusion.
- Design and run a replicated fair test on popcorn kernels, calculating percent popped and expansion volume.
- Write a full lab report in the standard format.

> **Warm-up.** Look at the bottom of a bowl of popcorn. Why didn't those kernels pop? Write down three possible reasons. Each one is a hypothesis you could test.

WATCH

Why Does Popcorn Pop? Tiny Explosion Explained!

History of Simple Things · 8:05

https://www.youtube.com/watch?v=HJjsKJJHIYY

> **WHEN TO WATCH**
> During session 1, after the story. Write down the role of the water inside the kernel; it is the key to your hypothesis.

KEY TERMS

controlled trial
An experiment that compares treatments in groups that are alike in every other way.

replication
Repeating each treatment more than once, so that chance differences can be seen and averaged out.

percent yield
The amount obtained divided by the most possible, times 100%.

pericarp
The hard, moisture-tight hull of a popcorn kernel.

lab report

A written record of an experiment: title, question, hypothesis, materials, procedure, data, analysis, conclusion and sources of error.

CORE IDEAS

The story. In the 1700s scurvy killed more British sailors than battle did. Its victims grew weak, their gums swelled and bled, and old wounds reopened. In May 1747 James Lind, a Scottish naval surgeon aboard HMS *Salisbury*, chose twelve sailors with scurvy whose cases were as alike as he could find. He housed them together, gave them all the same basic meals, and divided them into six pairs. Each pair received a different daily remedy: cider, a weak acid called elixir of vitriol, vinegar, sea water, a paste of spices, or two oranges and a lemon.

How they figured it out. Within six days the oranges and lemons ran out, but one of the two sailors who received them was fit for duty and the other had nearly recovered; the other pairs improved little. Lind published his findings in 1753 in *A Treatise of the Scurvy*. His trial was small and his explanation of the cause was wrong, but his method was powerful: similar subjects, one difference between groups, a fair comparison. It took until 1795 for the Royal Navy to issue lemon juice to all its sailors, and until the 1930s for scientists to identify vitamin C as the missing nutrient. A modern scientist reading Lind's report would ask four questions of it, and you should ask them of every report you read: What was the question? What was done? What was measured? Do the results support the conclusion?

The kitchen science. A popcorn kernel is a tiny pressure cooker. Its hard **pericarp** holds in moisture (ideally about 13–14 percent of the kernel's mass) around a core of starch. Heated to roughly 350–400 °F (175–205 °C), the water turns to steam, the starch softens, and the pressure inside rises until the hull bursts. The starch and steam foam outward and set into the white puff. Kernels that are too dry cannot build enough steam; kernels with cracked hulls let the steam leak out. That is a testable hypothesis: drier kernels pop less.

Think it through. Lind gave each remedy to two sailors. You will pop each treatment at least twice. Replication lets you see how much results vary by chance, so you can tell whether a difference between treatments is bigger than that random scatter.

Let's cook. After the experiment you will make a full batch of stovetop popcorn for the family. The skill is **controlling heat in a covered pot**: testing the oil with three kernels, shaking the pot, and venting steam so the popcorn stays crisp.

PICTURE STUDY



Portrait of James Lind, George Chalmers, 1783 · Oil on canvas (reproduced as an engraving) · Royal College of Physicians of Edinburgh

Image: Wikimedia Commons, public domain

James Lind (1716–1794) later became chief physician of the great naval hospital at Haslar, near Portsmouth. His trial of 1747 is often called one of the first controlled clinical trials.

Look closely

- Look at his expression. Does he look like a man who would trust an old remedy or test it?
- Look at his clothes and wig. What do they tell you about his position?
- Imagine the cramped space below decks where he ran his trial. What would make a fair comparison hard there?

Talk about it

1. Lind gave each remedy to only two sailors. Why is a larger number better?
2. Lind's method was right even though his explanation of scurvy was wrong. How is that possible?
3. What would Lind need to do to make his trial fairer by today's standards?

> **Safety first.** Hot oil and steam: use a heavy pot with a lid, keep the lid on while popping, tilt it away from your face when you vent or open it, and keep a lid-sized baking sheet and baking soda by the stove. Popcorn is a choking hazard for small children; keep it away from toddlers.

KITCHEN LAB

Why Don’t Some Kernels Pop?

You will test the hypothesis that drier kernels pop less, with two treatments and two trials each, and write your first full lab report.

You will need

- A heavy 3–4-quart pot with a lid
- A rimmed baking sheet
- A digital scale (0.1 g if possible), a 4-cup liquid measure and a 1-cup measure
- A large bowl and a sieve or colander to separate unpopped kernels
- Oven mitts
- Your lab notebook

Stovetop Popcorn

Serves 4 (about 12 cups) · Cook 8 min

Ingredients

- 3 tablespoons vegetable or canola oil
- ½ cup (100 g) popcorn kernels
- ¾ teaspoon fine salt
- Optional: 2 tablespoons melted butter, or 1 tablespoon grated parmesan with ½ teaspoon garlic powder

Method

1. Put the oil and 3 kernels in the pot, cover, and heat over medium-high heat.
2. When the 3 kernels pop, add the rest in one layer, cover, and take the pot off the heat for 30 seconds (this brings all the kernels to nearly the same temperature).
3. Return to the heat. When popping begins, shake the pot gently every few seconds, holding the lid on with a towel or mitt. Tilt the lid open a crack, away from you, to let steam out.

4. When popping slows to 2–3 seconds between pops, remove from the heat and pour into a large bowl.
5. Toss with salt (and butter or parmesan if using). Serve right away.
6. Let the pot cool, then wipe out the oil and wash it.

Allergy check: Contains none of the major allergens as written; butter adds milk and parmesan adds milk. Popcorn is not safe for young children because of choking.

Steps

1. **Read the report.** Read the story of Lind's trial again and write its question, method, measurement and conclusion in four lines.
2. **Hypothesis.** "If popcorn kernels are dried, then a smaller percentage will pop, because ...."
3. **Prepare.** Weigh 100.0 g of kernels onto a baking sheet and dry them in a 200 °F (93 °C) oven for 90 minutes; cool and reweigh. Keep 100.0 g of untreated kernels in a sealed jar as the control.
4. **Pop.** For each trial use exactly 50.0 g of kernels and 1 tablespoon of oil in the same pot on the same burner setting. Pop until there are 3 seconds between pops. Do two control trials and two dried trials, alternating them.
5. **Measure.** For each trial, measure the popped volume in cups and weigh the unpopped kernels (sift them out).
6. **Analyze.** Calculate percent popped and expansion ratio for every trial, then the mean for each treatment.
7. **Report.** Write a full lab report: title, question, hypothesis, materials, procedure, data table, calculations, conclusion and two sources of error.
8. **Cook for the family.** Make the full stovetop recipe with untreated kernels and serve it.
9. Clean up: cool and wash the pot, wipe the stove and counter.

Tips

- Old popcorn that pops poorly can sometimes be revived by sealing it in a jar with 1 tablespoon of water per pound for a few days.
- Do not crowd the pot: kernels should sit in a single layer in the oil.
- If the kitchen smells of scorched oil, the heat is too high. Lower it next trial.

Check your work

- ☐ I can describe Lind's trial and why it was a fair test.
- ☐ I ran a replicated experiment and calculated percent popped and expansion ratio.
- ☐ I wrote a complete lab report.

LAB NOTEBOOK

1. Draw a cross-section of a popcorn kernel before and after popping, labeling the pericarp, the starchy endosperm, the germ and the water.
2. Copy Lind's six treatments in a table and add a column saying what he observed for each.
3. Write the full lab report for the popcorn experiment.

KEY FORMULAS

$$\text{percent popped (by mass)} = \frac{m_{\text{start}} - m_{\text{unpopped}}}{m_{\text{start}}} \times 100\%$$

$$\text{expansion ratio} = \frac{V_{\text{popped}}}{V_{\text{kernels}}}$$

From history. Lind's idea of comparing treatments fairly grew into the modern randomized controlled trial; in 1948 Britain's Medical Research Council published a landmark trial of streptomycin for tuberculosis in which patients were assigned to treatments by chance. May 20, the day Lind is said to have begun his trial, is now marked in some countries as International Clinical Trials Day.

WORKED EXAMPLES

Example 1. You pop 50.0 g of kernels and 4.5 g remain unpopped. Find the percent popped by mass.

Show solution

1. $\dfrac{50.0 - 4.5}{50.0} \times 100\% = \dfrac{45.5}{50.0} \times 100\% = 91\%.$

Answer: 91% popped.

Example 2. Two trials of normal kernels give 91% and 89% popped. Two trials of oven-dried kernels give 62% and 70%. Find each mean and decide whether the difference is real.

Show solution

1. Normal: $\dfrac{91 + 89}{2} = 90\%$, range 2 percentage points.
2. Dried: $\dfrac{62 + 70}{2} = 66\%$, range 8 points.
3. Difference of means: 24 points, much larger than either range.

Answer: Means 90% and 66%. The difference is far larger than the trial-to-trial scatter, so drying really did reduce popping.

Example 3. ¼ cup (60 mL) of kernels pops into 7 cups of popcorn. Find the expansion ratio ($1 \text{ cup} = 240 \text{ mL}$).

Show solution

1. Popped volume: $7 \times 240 \text{ mL} = 1680 \text{ mL}$.
2. Ratio: $\dfrac{1680 \text{ mL}}{60 \text{ mL}} = 28$.

Answer: An expansion ratio of 28: the popcorn takes up 28 times the volume of the kernels.

Example 4. Kernels that weighed 50.0 g weigh 46.8 g after 90 minutes in a 200 °F oven. If they started at 14% moisture, estimate their new moisture content.

Show solution

1. Water at start: $0.14 \times 50.0 \text{ g} = 7.0 \text{ g}$; dry matter 43.0 g.
2. Water lost: $50.0 - 46.8 = 3.2 \text{ g}$, so water left $7.0 - 3.2 = 3.8 \text{ g}$.
3. New moisture: $\dfrac{3.8}{46.8} \times 100\% = 8.1\%$.

Answer: About 8% moisture, well below the 13–14% that pops best.

PRACTICE

1. Easy What were the six remedies in Lind's trial?

Show answer

Cider, elixir of vitriol, vinegar, sea water, a spice paste, and oranges and lemons.

2. Easy 50.0 g of kernels leave 6.0 g unpopped. Find the percent popped.

Show answer

$44.0/50.0 \times 100\% = 88\%$

3. Easy What is the purpose of the control group in the popcorn lab?

Show answer

It shows what normal kernels do under the same conditions, so the effect of drying can be measured against it.

4. Medium Why did Lind choose sailors whose illness was similar, and feed them the same meals?

Show answer

So the only difference among the groups was the remedy; then any difference in recovery could be credited to it.

5. Medium ½ cup of kernels pops into 15 cups. Find the expansion ratio.

Show answer

$15/0.5 = 30$

6. Medium Two control trials give 88% and 92%; two dried trials give 85% and 89%. Is drying having a clear effect? Explain.

Show answer

Means 90% and 87%. The 3-point difference is about the size of the scatter, so the effect is not clear; more trials are needed.

7. Medium Why does a kernel with a cracked hull usually fail to pop?

Show answer

Steam escapes through the crack, so pressure cannot build up enough to burst the hull.

8. Medium In what year did the Royal Navy begin to issue lemon juice to all its sailors, and when was vitamin C identified?

Show answer

1795; the 1930s.

9. Hard Kernels at 14% moisture weigh 60.0 g. How much water must they lose to fall to 10% moisture?

Show answer

Dry matter $0.86 \times 60 = 51.6$ g. At 10%, total $51.6 / 0.90 = 57.3$ g. Lose 2.7 g.

10. Hard List three controlled variables in the popcorn lab and explain how failing to control one could fool you.

Show answer

Kernel mass, oil amount, burner setting (also pot, stopping rule). If the dried kernels were popped on a lower burner, they might pop less because of the heat, not the drying.

11. Challenge A student pops dried kernels in all the first trials and control kernels in all the later ones. Why is that a problem, and how does alternating fix it?

Show answer

The pot gets hotter with each trial, so later trials pop better regardless of treatment. Alternating (control, dried, control, dried) spreads any warming effect over both treatments.

COMMON MISTAKES

- Running every trial of one treatment first, so the warming pot becomes a hidden variable.
- Changing the stopping rule between trials (some stopped early, some late).
- Reporting one trial and calling it a result.
- Leaving the lid fully closed after popping so steam makes the popcorn soggy.

> **Make it a game · Report Reader.** Your parent writes a four-sentence made-up lab report about popcorn on a card. Underline the question, method, results and conclusion in different ways within sixty seconds, and decide if the test could be replicated. Do three reports. Then tell how James Lind compared six scurvy treatments aboard HMS Salisbury in 1747.

> **Scripture.** “Prove all things; hold fast that which is good.” (1 Thessalonians 5:21, KJV)
>
> To prove a thing is to test it. Lind tested the remedies of his day and held fast to the one that worked.

UNIT 1

The Science of Food and Safe Lab Practice

Food science began in a confectioner's kitchen and grew into a field of chemists, microbiologists and engineers. In this first unit you will learn to work like a food scientist in your own kitchen: measuring by mass, changing one variable at a time, calibrating instruments, working safely with knives, heat and fire, and writing up what you did so someone else could repeat it.

Each lesson pairs a real story with a lab and a recipe: Nicolas Appert's sealed bottles and a banana bread baked entirely by weight; Ruth Wakefield's Toll House cookie and a butter experiment; George Manby's extinguisher, the fire triangle and a stir-fry; Fahrenheit and Celsius and a calibrated thermometer in roasted chicken thighs; and James Lind's scurvy trial with a replicated popcorn experiment. By the end you will have a lab notebook set up for the year and the habits that make every later lab safe and trustworthy.

PREREQUISITES

- Algebra I (or taking it now): solving simple equations, working with fractions, decimals and percentages
- Has used a stove and oven with a parent; this unit sets the safety standard for the year
- Has a digital kitchen scale that reads grams and an instant-read thermometer

MASTERY CHECKLIST

- ☐ I can tell how food science grew from Appert's practical discovery to a scientific field, and why scientists measure by mass.
- ☐ I can design a fair test with independent, dependent and controlled variables, and replicate it.
- ☐ I can calculate a mean, range, percent error, percent difference and a yield factor.
- ☐ I can explain the fire triangle, handle a grease fire correctly, use the claw and bridge grips, and mix a measured sanitizer.
- ☐ I can convert between °F and °C, calibrate a thermometer, and cook poultry to 165 °F.
- ☐ I can write a complete lab report.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FoodSafety.gov: Safe Minimum Internal Temperatures**: Free at FoodSafety.gov. A chart to tape inside a cupboard door; used all year.
- **King Arthur Baking: Ingredient Weight Chart**: Free. Grams per cup for hundreds of ingredients; the source of this course's 120 g cup of flour.
- **A digital kitchen scale that reads in 1-gram steps**: Required for the course. A model that reads 0.1 g is helpful for salt, yeast and the popcorn lab but not necessary.
- **A small ABC or BC fire extinguisher for the kitchen**: Many families already have one. Learn the PASS method (pull, aim, squeeze, sweep) with a parent.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

1.1	**From Appert to the IFT: What Food Science Is**	3 sessions of 50–90 minutes
1.2	**One Variable at a Time: The Cookie Experiment**	3 sessions of 50–90 minutes
1.3	**Safe Lab Practice: Knives, Heat, Fire and Sanitizer**	3 sessions of 50–90 minutes
1.4	**Fahrenheit, Celsius and the Calibrated Thermometer**	3 sessions of 50–90 minutes
1.5	**James Lind's Fair Test and the Popcorn Experiment**	3 sessions of 50–90 minutes

Unit 1 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   Why did Appert's bottled foods keep, and who explained it, and when?

2. **6 pts**

   Five scoops of flour weigh 136, 141, 139, 144 and 140 g. Find the mean, the range and the percent error compared with 120 g.

3. **6 pts**

   Convert 2 lb of flour to grams (1 lb = 453.6 g) and then to cups at 120 g per cup.

4. **7 pts**

   A student tests whether chilling dough changes cookie spread. Name the independent variable, two dependent variables, and four controlled variables, and write a hypothesis.

5. **6 pts**

   Scale a 36-cookie recipe that uses 270 g flour and 200 g sugar to make 90 cookies.

6. **6 pts**

   Batch A cookies have a mean diameter of 6.8 cm; batch B, 8.0 cm. Find the percent difference.

7. **8 pts**

   Describe step by step what you should do if oil catches fire in a skillet, and explain with the fire triangle why water must never be used.

8. **6 pts**

   You mix 1 tablespoon (15 mL) of 8.25% bleach into 1 gallon (3,785 mL) of water. Find the sodium hypochlorite concentration in ppm.

9. **4 pts**

   Why should you never mix bleach with vinegar or ammonia?

10. **6 pts**

    Convert 160 °F and 145 °F to Celsius, and say what each is the safe minimum for.

11. **6 pts**

    Estimate the boiling point of water at 6,000 ft in °F and °C.

12. **7 pts**

A thermometer reads 35 °F in ice water and 211 °F in boiling water at sea level. What is the true temperature when it reads 165 °F?

13. **6 pts**

Describe Lind's 1747 trial: the subjects, the groups, and the result.

14. **6 pts**

In the popcorn lab, 50.0 g of dried kernels leave 14.0 g unpopped, and 50.0 g of control kernels leave 4.0 g. Find each percent popped.

15. **4 pts**

Explain why replication matters, using the popcorn lab.

16. **10 pts**

Short essay (5–7 sentences): Choose one kitchen habit in your family (for example, how rice is cooked or how cookies are baked). Design a fair test that would improve it: state the question, hypothesis, independent, dependent and controlled variables, how many trials, and what you would measure.

ANSWER KEY

1. Heating the sealed bottles killed the microbes inside, and the seal kept new ones out. Appert did not know this; Louis Pasteur showed in the 1860s that microbes cause spoilage.
2. Mean $700/5 = 140$ g; range $144 - 136 = 8$ g; percent error $20/120 \times 100\% = 16.7\%$.
3. 907 g; $907/120 \approx 7.6$ cups.
4. Independent: chilled or not chilled. Dependent: diameter and thickness. Controlled: recipe, dough-ball mass, pan, oven temperature, baking time, rack position. Hypothesis: If the dough is chilled, the cookies will spread less, because the butter takes longer to melt and the proteins and starch set first.
5. Yield factor $90/36 = 2.5$; flour 675 g, sugar 500 g.
6. $1.2/7.4 \times 100\% = 16.2\%$
7. Turn off the burner, slide a lid or baking sheet over the pan and leave it; use baking soda for a small fire; if it grows, get out and call 911. This removes heat and oxygen. Water sinks under the oil, flashes to steam and throws burning oil outward.
8. $0.0825 \times 15 = 1.24$ mL; $1.24/3800 \times 10^6 \approx 326$ ppm. Use less bleach (about 2 tsp) for about 200–240 ppm.
9. The mixtures release toxic gases (chlorine with acids, chloramines with ammonia).
10. 71 °C: ground beef, pork, lamb and egg dishes. 63 °C: whole cuts of beef, pork, veal and lamb (with a 3-minute rest) and fish.
11. $212 - 12 = 200$ °F; $\frac{5}{9}(168) = 93$ °C.
12. Span 176 vs. true 180: $T = 32 + \frac{180}{176}(165 - 35) = 32 + 133.0 = 165.0$ °F. (It happens to be right at this point.)
13. Twelve sailors with similar scurvy, same meals, six pairs each given a different remedy (cider, elixir of vitriol, vinegar, sea water, spice paste, oranges and lemons). The pair given citrus recovered fastest.
14. Dried $36/50 = 72\%$; control $46/50 = 92\%$.
15. Results vary by chance from trial to trial. Repeating each treatment shows the size of that scatter, so you can tell whether a difference between treatments is real.

16. Answers vary. Full credit for a clear testable question, a hypothesis with a reason, one independent variable, a measurable dependent variable, at least three controlled variables, replication, and a plan for analysis.

UNIT PROJECT: MY KITCHEN LAB MANUAL

Assemble the front section of your lab notebook as a manual for the year: your family kitchen safety audit (with fixes made), your thermometer calibration record, a one-page fire and burn response card to post inside a cupboard door, and a clean copy of your best lab report from this unit.

Then design and run one new fair test of your own on a simple recipe from this unit (for example, chilled vs. unchilled cookie dough, or two brands of popcorn) with at least two trials per treatment, and write a complete report with a data table, calculations and a conclusion.

LOOK FOR	WHAT IT MEANS
Safety	Audit completed honestly with real fixes; fire and burn card accurate (lid, heat off, never water; cool running water for minor burns).
Measurement	Masses in grams, temperatures calibrated and converted correctly, units on every number.
Experimental design	One independent variable, controlled variables listed, replication, alternating trials where it matters.
Analysis and honesty	Correct means, ranges and percent differences; results reported as they happened, including surprises.
Report and cleanup	Complete, readable report; kitchen left clean and sanitized after every lab.

UNIT 2

Water and Heat

Almost every food is mostly water, and almost every recipe heats or cools it. This unit is about the molecule at the center of cooking and the energy that changes it. You will learn why water dissolves sugar and salt so well, why it takes so much energy to heat and even more to boil, why steam burns are so dangerous, why water boils cooler in the mountains and hotter in a pressure cooker, and how heat moves into food by conduction, convection and radiation.

The stories run from Cavendish's balance and Count Rumford's cannon to Joseph Black's melting ice, Denis Papin's digester and Percy Spencer's melted candy bar. The labs are real measurements: solubility, burner power, a heating curve, your own boiling point and a toasting experiment. The recipes are lemonade, pasta, steamed fish, black beans and a sheet-pan dinner. Along the way you will use $q = mc\Delta T$, $q = mL$ and the conduction formula with units in every line.

PREREQUISITES

- Unit 1: measuring by mass, calibrated thermometer, °F ↔ °C conversions, lab report format
- Algebra: solving a linear equation for an unknown, working with scientific notation
- Comfortable using the stove and oven with a parent at home

MASTERY CHECKLIST

- ☐ I can explain water's polarity and hydrogen bonds and use them to explain dissolving, specific heat and boiling.
- ☐ I can calculate heat with $q = mc\Delta T$ and $q = mL$, and power with $P = q/t$.
- ☐ I can explain latent heat, read a heating curve, and explain why steam burns are severe.
- ☐ I can explain how pressure and altitude set the boiling point and how a pressure cooker works.
- ☐ I can explain conduction, convection and radiation (including microwaves) with kitchen examples.
- ☐ I cooked pasta, steamed fish, beans and a sheet-pan dinner safely and recorded the labs.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **USDA FSIS: High Altitude Cooking and Food Safety**: Free on the USDA Food Safety and Inspection Service website (fsis.usda.gov). How altitude changes boiling points and cooking times. For Lesson 2.4.
- **A pressure cooker (stovetop or electric)**: Optional. Lesson 2.4 works by simmering; a pressure cooker shortens the beans to minutes and makes the boiling-point science concrete. Always used with a parent present.
- **A steamer basket**: Inexpensive and useful all year. A metal colander set over a pot with a lid works for Lesson 2.3.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

2.1 Water: The Molecule That Cooks — 3 sessions of 50–90 minutes

2.2 Count Rumford and Specific Heat — 3 sessions of 50–90 minutes

2.3 Joseph Black, Latent Heat and the Steam Burn — 3 sessions of 50–90 minutes

2.4 Denis Papin's Digester: Pressure and the Boiling Point
3 sessions of 50–90 minutes (plus overnight soaking)

2.5 Conduction, Convection and Radiation: Percy Spencer's Melted Candy Bar
3 sessions of 50–90 minutes

Unit 2 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **5 pts**
   Explain what Cavendish and Lavoisier showed about water in the 1780s.

2. **6 pts**

   Describe water’s polarity and hydrogen bonding, and use them to explain why sugar dissolves well but oil does not.

3. **6 pts**

   Find the mass percent of a syrup made with 300 g sugar and 200 g water.

4. **6 pts**

   How much energy heats 3.0 kg of water from 18 °C to 100 °C?

5. **6 pts**

   A burner heats 1,500 g of water from 20 °C to 70 °C in 8.0 minutes. Find the power delivered to the water.

6. **6 pts**

   Describe Rumford’s cannon-boring experiment and what it showed.

7. **7 pts**

   500 g of pasta at 20 °C ($c = 1.8$ J/(g·°C)) is added to 3,000 g of water at 100 °C. Find the temperature after mixing, ignoring the burner.

8. **7 pts**

   Find the total energy to turn 200 g of ice at 0 °C into steam at 100 °C.

9. **7 pts**

   Explain with numbers why steam at 100 °C causes a worse burn than water at 100 °C.

10. **6 pts**

    What did Joseph Black observe about ice and water in a warm room, and what did he conclude?

11. **6 pts**

    Estimate the boiling point of water at 8,000 ft in °F and °C. Will pasta cook faster or slower there?

12. **7 pts**

    A pressure cooker raises the boiling point to 121 °C. Using the doubling-per-10 °C rule, estimate how long a stew that needs 2 hours at 100 °C would take.

13. **5 pts**

    Why is Papin’s safety valve important, and how does it work?

14. **6 pts**

    Find the wavelength of 2.45-GHz microwaves and explain how they heat food.

15. **4 pts**

    Name the main kind of heat transfer in each: a pancake on a griddle; potatoes in boiling water; toast under a broiler.

16. **10 pts**

    Short essay (5–7 sentences): Explain to a younger cook why a pot of boiling water never gets hotter than its boiling point, why it boils sooner with the lid on, why a big pot cooks pasta better, and how to open the lid safely. Use the words specific heat, latent heat and steam.

ANSWER KEY

1. Water is not an element but a compound of hydrogen and oxygen: Cavendish formed water by burning hydrogen in air (1781); Lavoisier decomposed and recombined it and named hydrogen (1783).
2. Oxygen pulls shared electrons, leaving the oxygen end slightly negative and the hydrogens slightly positive; neighboring molecules attract by hydrogen bonds. Sugar's –OH groups hydrogen-bond with water, so it dissolves; nonpolar oil cannot, and water squeezes it out.
3. $300/500 = 60\%$
4. $(3000)(4.18)(82) = 1.03 \times 10^6$ J
5. $q = (1500)(4.18)(50) = 313{,}500$ J; $P = 313{,}500/480 = 653$ W.
6. A blunt borer turned against a cannon in a box of water, driven by horses, boiled the water in about 2.5 hours with no fire. The heat seemed unlimited as long as work continued, so heat is a form of motion, not a fluid (caloric).
7. $(3000)(4.18)(100 - T) = (500)(1.8)(T - 20)$; $1{,}254{,}000 + 18{,}000 = 13{,}440\,T$, $T = 94.6\ ^\circ\text{C}$.
8. $200(334) + 200(4.18)(100) + 200(2260) = 66{,}800 + 83{,}600 + 452{,}000 = 602{,}400$ J
9. Each gram of steam releases 2,260 J as it condenses, then about 263 J cooling to body temperature (total about 2,520 J), compared with about 263 J for water: nearly ten times the heat.
10. Ice-cold water warmed several degrees in half an hour, while the same mass of ice stayed at the freezing point for about ten and a half hours as it melted, so melting absorbs a large amount of heat without changing temperature: latent heat.
11. $212 - 16 = 196\ ^\circ\text{F} \approx 91\ ^\circ\text{C}$; slower, because the water is cooler.
12. $2^{2.1} = 4.3$; $120\ \text{min}/4.3 \approx 28$ min.
13. It keeps the pressure from rising high enough to burst the vessel: a weight (or spring) holds a small valve shut until the steam pressure pushes it open and lets steam escape.
14. $\lambda = 3.00 \times 10^8/2.45 \times 10^9 = 0.122$ m. They make polar water molecules rotate back and forth rapidly in the outer 1–2 cm of food; the rest heats by conduction.
15. Conduction; convection; radiation.
16. Answers vary. Full credit for: extra energy goes into latent heat of vaporization so the temperature stays at the boiling point; the lid traps hot vapor and reduces

heat loss; a large mass of water stores more heat (high specific heat) so it drops less when pasta goes in; steam releases latent heat when it condenses, so lift the lid away from you.

UNIT PROJECT: THE FAMILY ENERGY NOTEBOOK

Choose three dishes your family cooks often (for example, pasta, rice and soup). For each, measure the mass of water used, the starting and final temperatures, and the time on the burner, and calculate the energy that went into the water and the power delivered.

Then test one change that could save time or energy for one of the dishes (a lid, less water, a smaller burner after boiling, a pressure cooker, or a microwave) with two trials each way. Write a two-page report with your data, calculations, a graph and a recommendation for your family, and cook the improved dish for a family meal.

LOOK FOR	WHAT IT MEANS
Measurements	Masses, temperatures and times recorded honestly with units; thermometer calibration applied.
Calculations	$q = mc\Delta T$, $q = mL$ and $P = q/t$ used correctly, with every step and unit shown.
Fair test	One change tested at a time, with two trials each way and other conditions controlled.
Recommendation	A clear, practical recommendation supported by the data, including any limits or surprises.
Safety and cleanup	Hot pots, steam and lids handled safely; kitchen clean after each trial.

2.1 Water: The Molecule That Cooks

OBJECTIVES

- Tell how Henry Cavendish and Antoine Lavoisier showed in the 1780s that water is a compound of hydrogen and oxygen.
- Explain polarity and hydrogen bonding, and use them to explain why water dissolves sugar and salt.
- Measure the solubility of sugar and salt in cold and hot water, and calculate concentrations in a lemonade.

> **Warm-up.** Put a teaspoon of sugar in a glass of iced water and another in a glass of hot tap water. Stir each ten times. Which dissolves faster? Now guess: if you kept adding sugar, which glass could hold more?

WATCH

Properties of Water

Amoeba Sisters · 6:51

https://www.youtube.com/watch?v=3jwAGWky98c

> **WHEN TO WATCH**
> During session 1. Pause at each property (cohesion, adhesion, solvent, specific heat) and write one kitchen example of it.

KEY TERMS

polar molecule

A molecule with a slightly negative end and a slightly positive end. In water, oxygen pulls the shared electrons toward itself.

hydrogen bond

A weak attraction between a slightly positive hydrogen on one molecule and a slightly negative atom (such as oxygen) on another.

solvent and solute

The solvent is the substance that does the dissolving (water); the solute is what dissolves (sugar, salt).

solubility

The most solute that will dissolve in a given amount of solvent at a given temperature, often given in grams per 100 g of water.

saturated solution

A solution holding all the solute it can at that temperature; extra solute stays undissolved.

concentration (mass percent)

The mass of solute divided by the mass of the whole solution, times 100%.

CORE IDEAS

The story. For two thousand years, educated people believed water was an element, one of the four from which everything was made. In 1781 the shy English chemist Henry Cavendish burned "inflammable air" (hydrogen) in ordinary air inside a sealed glass vessel and found dew forming on the walls: pure water. In Paris, Antoine Lavoisier repeated and extended the work in 1783, decomposing water and recombining it, and named the inflammable gas *hydrogène*, "water-maker." Water was not an element after all, but a compound: two parts hydrogen to one part oxygen, H_2O.

How they figured it out. Cavendish's secret was the balance. He weighed his gases carefully and found that the water formed had the same mass as the gases that disappeared. Lavoisier made that idea a law: in a chemical reaction mass is neither created nor destroyed. Both men measured first and theorized second, the habit you began in Unit 1.

The kitchen science. In a water molecule, oxygen pulls the shared electrons toward itself, so the oxygen end is slightly negative and the two hydrogens slightly positive: water is **polar**. Neighboring molecules cling to each other through **hydrogen bonds**. Those bonds explain almost everything water does in a kitchen: why it takes so much energy to heat (Lesson 2.2) and to boil (Lesson 2.3), why it beads and clings, and why it dissolves so many foods. Sugar molecules are covered with –OH groups that hydrogen-bond with water, so sugar dissolves enormously: about 200 g of table sugar in 100 g of water at room temperature, and nearly 490 g at the boiling point. Salt dissolves differently: water molecules surround and pull apart the charged sodium and chloride ions. Its solubility barely changes with temperature, about 36 g per 100 g of water cold and 39 g hot. Oil molecules are nonpolar; water molecules hold onto each other and squeeze the oil out, which is why oil and water separate (Unit 5).

Let's cook. You will make a **simple syrup** by dissolving sugar in hot water, and use it to make lemonade. Syrup is how cooks get sugar to dissolve evenly into cold drinks,

where it dissolves slowly. The skill is **measuring concentrations** so the drink can be made the same way every time.

PICTURE STUDY



The Copper Drinking Fountain, Jean-Siméon Chardin, c. 1734 · Oil on panel · Musée du Louvre, Paris

Image: Wikimedia Commons, public domain

Before running water, a Paris kitchen kept its water in a copper cistern, filled by hand from a well or a water-carrier. Chardin painted this humble object as carefully as a portrait.

Look closely

- Find the tap. How would a cook draw water from it?
- Find the pitcher and the ladle. What jobs in a kitchen need water every day?
- Look at the copper. Why might a cook choose copper for a water vessel?
- Notice the light on the metal and the shadows on the wall. Where is the light coming from?

Talk about it

1. Count how many times you used water in your kitchen today: washing, boiling, dissolving, cleaning. What would cooking be like if every drop had to be carried?
2. Why is it a good thing that water dissolves so many substances? When is it a problem?
3. Chardin made an ordinary object beautiful by looking closely. What would a scientist learn by looking this closely at water?

> **Safety first.** Hot syrup holds a lot of heat and sticks to skin: heat it gently, stir with a long spoon, and let it cool before tasting. Squeeze lemons on a board with a damp towel underneath, and cut them with a sharp knife using the claw grip.

KITCHEN LAB

The Solubility Lab and Fresh Lemonade

Does hot water dissolve more sugar and more salt than cold water? You will find out by adding solute a little at a time until no more dissolves, and then put your sugar data to work in a lemonade.

You will need

- A digital scale
- Four clear glasses or jars
- A thermometer
- Teaspoons and a stirring spoon
- A small saucepan
- A citrus juicer or fork, a knife and a cutting board
- A 2-quart pitcher
- Your lab notebook

Fresh Lemonade from Simple Syrup

Serves About 6 cups (6 servings) · Prep 20 min · Chill 1 hr

Ingredients

- 200 g (1 cup) sugar
- 240 g (1 cup) water for the syrup
- 240 mL (1 cup) fresh lemon juice (5–7 lemons)
- 960 mL (4 cups) cold water
- Ice and lemon slices for serving

Method

1. Wash the lemons under running water. Roll each one firmly on the counter, cut it in half, and squeeze out the juice; strain out seeds.
2. Make the syrup: heat the sugar and 1 cup water in the saucepan over medium heat, stirring, just until the sugar dissolves and the liquid is clear. Do not boil it hard. Cool it.

3. Combine the cooled syrup, lemon juice and cold water in the pitcher. Taste and adjust with more water if too strong.
4. Chill at least 1 hour. Serve over ice with lemon slices.
5. Wash the saucepan, juicer and board.

Allergy check: Contains none of the major allergens. For less sugar, start with half the syrup and taste; the remaining syrup keeps in the refrigerator for 2 weeks.

Steps

1. **Hypothesis.** Predict whether temperature will change the solubility of sugar, of salt, or both, and why.
2. **Sugar, cool.** Weigh 50 g of room-temperature water into a glass. Add sugar 10 g at a time, stirring 1 minute after each addition, until some will not dissolve. Record the total that dissolved.
3. **Sugar, hot.** Repeat with 50 g of water heated to about 160 °F (70 °C) in the saucepan and poured into a heat-safe glass. Keep track of the temperature.
4. **Salt, cool and hot.** Repeat both tests with salt, adding 2 g at a time.
5. **Analyze.** Convert each result to grams per 100 g water and compare with the accepted values (sugar about 200 g cold, salt about 36 g cold and 37–38 g at 70 °C).
6. **Make the lemonade** and calculate its sugar concentration and the sugar in one cup.
7. **Conclusion.** Explain your results with polarity and hydrogen bonding. Why did sugar respond to temperature so much more than salt?
8. Clean up: the sugar solutions can be saved as syrup in a clean jar; pour the salt solutions down the drain and wash everything.

Tips

- Microwaving a lemon for 10–15 seconds before squeezing helps release more juice.
- Stir every sample the same number of times; stirring speed is a hidden variable in dissolving.
- As the hot sugar solution cools, watch for crystals. You have made a supersaturated solution.

Check your work

- ☐ I can explain polarity and hydrogen bonds and how water dissolves sugar and salt.
- ☐ I measured solubility and compared it with accepted values.
- ☐ I calculated the concentration of a solution I made.

LAB NOTEBOOK

1. Draw three water molecules hydrogen-bonded to each other, with δ+ and δ− marked, and a sugar molecule's –OH groups bonding to water.
2. Graph your solubility data: grams per 100 g water against temperature, one line for sugar and one for salt.
3. Copy the lemonade recipe with its concentration calculation.

KEY FORMULAS

$$\text{mass percent} = \frac{m_{\text{solute}}}{m_{\text{solute}} + m_{\text{solvent}}} \times 100\%$$

$$\text{molar mass of } \mathrm{H_2O} = 2(1.008) + 16.00 = 18.02 \text{ g/mol}$$

From history. James Watt in Scotland also concluded that water was a compound, and for a time there was a friendly dispute over who deserved the credit. Today the credit is usually shared: Cavendish for the experiment, Lavoisier for the interpretation.

WORKED EXAMPLES

Example 1. A simple syrup is made from 200 g of sugar and 240 g of water. Find its sugar concentration by mass.

Show solution

1. $\dfrac{200 \text{ g}}{200 \text{ g} + 240 \text{ g}} \times 100\% = \dfrac{200}{440} \times 100\% = 45.5\%.$

Answer: About 45% sugar by mass.

Example 2. The whole lemonade contains 200 g sugar in about 1,520 g of liquid in total (syrup, lemon juice and water). Find the sugar concentration, and the grams of sugar in one 240-g (1-cup) serving.

Show solution

1. Concentration: $\dfrac{200\ \text{g}}{1520\ \text{g}} \times 100\% = 13.2\%$.
2. Per serving: $0.132 \times 240\ \text{g} = 31.7\ \text{g}$.

Answer: About 13% sugar; about 32 g of sugar per cup, or roughly 8 teaspoons (4 g per teaspoon). A treat, best in its place.

Example 3. What fraction of a water molecule's mass is hydrogen? How many grams of hydrogen are in 18 g of water?

Show solution

1. Hydrogen: $\dfrac{2(1.008)}{18.02} = 0.112 = 11.2\%$.
2. In 18 g: $0.112 \times 18\ \text{g} = 2.0\ \text{g}$.

Answer: 11.2% hydrogen by mass; about 2.0 g of hydrogen in 18 g of water, as Cavendish's balance would show.

Example 4. Salt dissolves to about 36 g per 100 g of water at room temperature. What is the greatest possible mass percent of salt in brine at that temperature?

Show solution

1. $\dfrac{36\ \text{g}}{36\ \text{g} + 100\ \text{g}} \times 100\% = 26.5\%$.

Answer: About 26%. A saturated brine can never be stronger than this at room temperature.

PRACTICE

1. Easy What did Cavendish observe when he burned hydrogen in air in 1781?

   Show answer

   Water formed on the walls of the vessel.

2. **Easy** Which end of a water molecule is slightly negative?

   Show answer

   The oxygen end.

3. **Easy** Find the mass percent of 25 g of sugar dissolved in 225 g of water.

   Show answer

   $25/250 = 10\%$

4. **Medium** Explain in two sentences why oil does not dissolve in water.

   Show answer

   Oil molecules are nonpolar and cannot form hydrogen bonds. Water molecules attract each other more strongly than they attract oil, so they squeeze the oil out into a separate layer.

5. **Medium** How many grams of sugar are needed to make 500 g of a 20% sugar solution? How much water?

   Show answer

   $0.20 \times 500 = 100$ g sugar and 400 g water.

6. **Medium** Find the molar mass of sucrose, $C_{12}H_{22}O_{11}$ (C = 12.01, H = 1.008, O = 16.00).

   Show answer

   $144.12 + 22.18 + 176.00 = 342.3$ g/mol

7. **Medium** A recipe's lemonade has 30 g of sugar per cup. How many teaspoons is that (4 g per teaspoon)?

   Show answer

   $30/4 = 7.5$ teaspoons.

8. **Medium** Why do cooks dissolve sugar into a syrup before adding it to iced drinks?

   Show answer

   Sugar dissolves much faster in hot water; in a cold drink it settles undissolved at the bottom.

9. Hard At 100 °C about 487 g of sugar dissolves in 100 g water. You make a saturated syrup at 100 °C and cool it to 20 °C, where solubility is 200 g. If nothing crystallizes, by how many grams is it supersaturated?

Show answer

$487 - 200 = 287$ g per 100 g water. It is very unstable; a crystal or a stir can make sugar crystallize out.

10. Hard How many moles of water are in one cup (240 g)? How many molecules (6.02×10^{23} per mole)?

Show answer

$240 / 18.02 = 13.3$ mol; $13.3 \times 6.02 \times 10^{23} = 8.0 \times 10^{24}$ molecules.

11. Challenge A cook dissolves 30 g of salt into 1 L (1,000 g) of water for boiling pasta. Is this "as salty as the sea" (sea water is about 3.5% salt)? Show work.

Show answer

$30 / 1030 = 2.9\%$, a little less salty than the sea.

COMMON MISTAKES

- Boiling simple syrup hard. Water evaporates and the syrup becomes thicker and stronger than the recipe expects.
- Confusing "dissolving" with "melting." Sugar in water dissolves; sugar in a hot dry pan melts.
- Adding salt to cold water and assuming it will all dissolve however much you add.

> **Make it a game · Drops on a Penny.** Predict how many drops of water fit on a penny before they spill over. Count, then try with one drop of dish soap in the water. Record both numbers and explain the gap using polarity and hydrogen bonds. Run it three times for the mean. Then tell how Cavendish and Lavoisier showed water is a compound.

2.2 Count Rumford and Specific Heat

OBJECTIVES

- Tell how Count Rumford's cannon-boring experiment in Munich (1798) showed that heat is a kind of motion, not a fluid.
- Use q = mcΔT to calculate the energy needed to heat water and oil, and estimate the power of a stove burner.
- Cook pasta and explain with calculations why cooks use plenty of water.

> **Warm-up.** Put a metal spoon, a wooden spoon and a cup of water in a sunny window or near (not on) a warm stove for 10 minutes. Touch each. Which feels warmest? Which really is warmest? Predict which would take longest to heat.

WATCH

Specific heat in cooking

Harvard Online · 3:59

https://www.youtube.com/watch?v=vuHlQHvF84Y

> **WHEN TO WATCH**
> During session 1, after the story. Copy the formula and the worked example for heating a cup of water; you will use the same method in the lab.

KEY TERMS

heat (q)

Energy that moves from a hotter object to a colder one, measured in joules (J) or calories.

specific heat capacity (c)

The energy needed to raise 1 g of a substance by 1 °C. For water, 4.18 J/(g·°C).

joule (J)

The SI unit of energy. 4.184 J = 1 calorie (small c); 1 food Calorie = 1 kcal = 4,184 J.

power

Energy per unit time, measured in watts (1 W = 1 J/s).

caloric theory

The old, mistaken idea that heat is an invisible fluid that flows from hot to cold.

CORE IDEAS

The story. Benjamin Thompson was born in Woburn, Massachusetts, in 1753, sided with the British in the War of Independence, and ended up in the service of the Elector of Bavaria, who made him Count Rumford. In Munich he reorganized the army, fed the city's poor with a cheap, nourishing barley-and-pea soup, and redesigned kitchens with enclosed stoves that wasted far less fuel. In 1798, supervising the boring of cannon barrels at the Munich arsenal, he noticed how astonishingly hot the metal and the shavings became.

How they figured it out. Most scientists then held the **caloric theory**: heat was a fluid squeezed out of matter. Rumford set up a test. He immersed a blunt borer turning against a cannon in a box of water, driven by horses. After about two and a half hours the water boiled, with no fire at all, to the astonishment of onlookers. The heat seemed to have no limit as long as the horses kept turning, which a fixed store of fluid could not explain. Rumford concluded that heat must be a kind of *motion*. Half a century later James Joule measured exactly how much mechanical work makes how much heat, and the caloric theory was gone.

The kitchen science. Heat is the energy of moving molecules. The energy needed to warm something is $q = mc\Delta T$: mass times specific heat times temperature change. Water's specific heat, 4.18 J/(g·°C), is unusually high because its hydrogen bonds soak up energy, so water heats slowly and holds heat well. Cooking oil's is only about 2.0 J/(g·°C), so the same mass of oil heats about twice as fast on the same burner (one reason a pan of oil gets dangerously hot quickly). When you drop a pound of cold pasta into boiling water, the pasta takes heat from the water and the temperature drops; a large pot of water has more stored energy, drops less, and comes back to the boil sooner, so the pasta cooks evenly instead of sitting in warm water and turning gummy.

Let's cook. You will cook spaghetti with garlic, olive oil and parmesan. The skill is **cooking pasta al dente**: plenty of well-salted water at a full boil, stirring in the first

minute, tasting from a minute before the package time, and saving a cup of the starchy cooking water to make the sauce cling.

PICTURE STUDY



Sir Benjamin Thompson, later Count Rumford, Thomas Gainsborough, 1783 · Oil on canvas · Harvard Art Museums (Fogg Museum), Cambridge, Massachusetts

Image: Wikimedia Commons, public domain

Gainsborough painted Thompson in 1783, the year he left England for Bavaria. He became one of the most practical scientists who ever lived, inventing improved stoves, a drip coffeepot, the Rumford fireplace and a famous cheap soup for the poor.

Look closely

- Look at his uniform. What does it tell you about his life at this time?
- Look at his face and pose. Does he seem confident? Curious?
- Notice Gainsborough's loose, quick brushstrokes in the background. How do they compare with the detail of the face?

Talk about it

1. Rumford saw the heat in cannon boring as a clue rather than a nuisance. What everyday kitchen observation might be a clue to a bigger idea?
2. Rumford designed stoves to save fuel for the poor. How does knowing $q = mc\Delta T$ help a cook save energy?
3. Why do you think the caloric theory lasted so long before Rumford and Joule overturned it?

> **Safety first.** Carry a full pot of boiling water with both hands and oven mitts, or drain pasta by lifting it out with tongs or a spider so you do not carry the pot. Pour away from yourself into a colander set in the sink. When heating oil for the lab, stay at the stove, use a thermometer, keep a lid ready, and stop well below the smoke point.

KITCHEN LAB

Measuring Heat: Burner Power and the Pasta Pot

You will measure how much power your burner actually delivers, compare how fast water and oil heat, and test how pot size affects the temperature drop when pasta goes in.

You will need

- A large pot (6–8 qt) and a medium saucepan
- A digital scale, an instant-read thermometer and a timer
- A colander and tongs or a spider
- A large skillet
- Oven mitts
- Your lab notebook

Spaghetti with Garlic, Olive Oil and Parmesan

Serves 4–6 · Prep 10 min · Cook 15 min

Ingredients

- 1 lb (450 g) spaghetti
- 4 quarts (about 4 L) water and 1½ tablespoons (about 25 g) salt
- ⅓ cup (75 mL) olive oil
- 6 cloves garlic, thinly sliced
- ¼ teaspoon red pepper flakes (optional)
- ¼ cup chopped fresh parsley
- ¾ cup (60 g) finely grated parmesan, plus more for serving
- Optional: 3 cups broccoli florets, added to the pasta water for the last 3 minutes

Method

1. Bring the water to a full rolling boil in the large pot with the lid on (it boils sooner). Add the salt.

2. Add the spaghetti and stir for the first minute so it does not stick. Boil uncovered, stirring now and then. Begin tasting 1 minute before the package time; it is done when tender but still slightly firm in the center (al dente).
3. Meanwhile, warm the olive oil and garlic in the skillet over medium-low heat until the garlic is pale gold, 3–4 minutes. Add the pepper flakes and turn off the heat. Do not let the garlic brown dark; it turns bitter.
4. Before draining, scoop out 1 cup of the cooking water. Drain the pasta (and broccoli, if using).
5. Add the pasta to the skillet with ½ cup of the reserved water and the parmesan. Toss over low heat for 1 minute until glossy, adding more water if dry. Add the parsley and serve.
6. Cool the pot before washing it. Wash the skillet, colander and tongs, and wipe the stove.

Allergy check: Contains wheat (pasta) and milk (parmesan). For wheat-free, use a gluten-free pasta; for milk-free, leave out the cheese and add toasted breadcrumbs (wheat) or more parsley and lemon.

Steps

1. **Burner power.** Weigh exactly 1,000 g of cold water into the saucepan. Record the starting temperature. Heat on high with no lid, stirring gently, and record the temperature every minute until 80 °C (176 °F). Calculate the average power delivered.
2. **Water vs. oil.** With a parent present, repeat with 250 g of vegetable oil in the same pan on the same setting, from room temperature to 80 °C only, recording every 30 seconds. Then cool the oil and save it for cooking. Compare the heating rates and calculate oil's specific heat from your data.
3. **Pasta-pot test.** Bring the 4 quarts of water to a boil. Record its temperature, add the spaghetti, and record the temperature every 30 seconds until it boils again. (If you can, repeat another day with 2 quarts and half a pound of pasta, and compare.)
4. **Cook** the recipe and serve it.
5. **Analyze.** Compare your temperature drop with the prediction from Worked Example 3. Explain any difference (the burner keeps adding heat; the pot

itself holds heat).

6. **Conclusion.** Write three sentences on what q = mcΔT tells a cook about pot size, oil safety and fuel.
7. Clean up: cool everything before washing; wipe up any oil spills right away.

Tips

- A lid traps hot vapor and cuts the time to boil; take it off once pasta is in, or it may boil over.
- Salt in the pasta water seasons the pasta from inside. It raises the boiling point by only a fraction of a degree.
- Keep your thermometer probe off the bottom of the pan, which is hotter than the liquid.

Check your work

- ☐ I can use q = mcΔT and P = q/t with units.
- ☐ I measured my burner's power and compared water and oil.
- ☐ I cooked pasta al dente and explained why a big pot helps.

LAB NOTEBOOK

1. Draw Rumford's cannon-boring setup: horses, the turning borer, the cannon and the box of water, with the time it took to boil.
2. Graph temperature against time for water and oil on the same axes, and label which line is steeper and why.
3. Record the pasta-pot temperature log and the recipe in your own words.

KEY FORMULAS

$$q = mc\Delta T$$

$$P = \frac{q}{t}$$

$$m_1 c_1 (T_1 - T_f) = m_2 c_2 (T_f - T_2)$$

From history. Rumford's soup for the poor of Munich was made of pearl barley, dried peas, potatoes, bread and salt, simmered long and slowly to save fuel. Versions of "Rumford soup" were served in soup kitchens across Europe for a century. He also founded the Royal Institution in London (1799), where Humphry Davy and Michael Faraday later worked.

Example 1. How much energy does it take to heat 4.0 kg (about 4 quarts) of water from 20 °C to 100 °C?

Show solution

1. $q = mc\Delta T = (4000\ \text{g})\left(4.18\ \frac{\text{J}}{\text{g}\cdot^\circ\text{C}}\right)(80\ ^\circ\text{C})$
2. $q = 1{,}337{,}600\ \text{J} = 1.34 \times 10^6\ \text{J} = 1.34\ \text{MJ}.$

Answer: About 1.34 million joules (1.34 MJ).

Example 2. A burner heats 1,000 g of water from 20 °C to 80 °C in 6.0 minutes. Estimate the power delivered to the water.

Show solution

1. Energy: $q = (1000)(4.18)(60)\ \text{J} = 250{,}800\ \text{J}.$
2. Time: $6.0\ \text{min} = 360\ \text{s}.$
3. Power: $P = \dfrac{250{,}800\ \text{J}}{360\ \text{s}} = 697\ \text{W}.$

Answer: About 700 W reaches the water. A burner rated at 2,000–2,500 W loses much of its heat to the air and the pot.

Example 3. You add 450 g of dry pasta at 20 °C to 4,000 g of boiling water at 100 °C. Estimate the temperature right after mixing. Take the pasta's specific heat as 1.8 J/(g·°C) and ignore heat from the burner.

Show solution

1. Heat lost by water = heat gained by pasta:
   $(4000)(4.18)(100 - T_f) = (450)(1.8)(T_f - 20).$
2. $16{,}720(100 - T_f) = 810(T_f - 20)$
3. $1{,}672{,}000 + 16{,}200 = 17{,}530\,T_f \ \Rightarrow\ T_f = 96.3\ ^\circ\text{C}.$

Answer: About 96 °C, only 4 °C below boiling. In 2,000 g of water the same calculation gives about 93 °C, a bigger drop and a slower return to the boil.

Example 4. The same 700-W burner heats 500 g of oil (c = 2.0 J/(g·°C)) from 20 °C. How long until the oil reaches 180 °C, the temperature for shallow frying?

Show solution

1. $q = (500)(2.0)(160)\ \text{J} = 160{,}000\ \text{J}$.
2. $t = \dfrac{q}{P} = \dfrac{160{,}000\ \text{J}}{700\ \text{W}} = 229\ \text{s} \approx 3.8\ \text{min}$.

Answer: Under 4 minutes. Oil heats fast and does not boil to warn you; never leave a pan of oil on the heat.

PRACTICE

1. Easy How much energy raises 1 g of water by 1 °C? By 10 °C?

   Show answer

   4.18 J; 41.8 J.

2. Easy Convert 1 food Calorie (1 kcal) to joules.

   Show answer

   4,184 J.

3. Easy What did Rumford conclude about heat in 1798?

   Show answer

   That heat is a form of motion, not a fluid (caloric), because friction produced heat without limit.

4. Medium Find the energy to heat 2,000 g of water from 15 °C to 100 °C.

   Show answer

   $(2000)(4.18)(85) = 710{,}600\ \text{J} \approx 0.71\ \text{MJ}$

5. Medium A 1,000-W microwave delivers all its power to 250 g of water at 20 °C. How long to reach 100 °C?

   Show answer

   $q = (250)(4.18)(80) = 83{,}600\ \text{J}$; $t = 83.6\ \text{s}$.

6. **Medium** 300 g of oil absorbs 48,000 J and rises from 20 °C to 100 °C. Find its specific heat.

   Show answer

   $c = 48{,}000/(300 \times 80) = 2.0\ \text{J/(g·°C)}$

7. **Medium** Why does a large pot of water make better pasta than a small one?

   Show answer

   It stores more heat, so the temperature drops less when cold pasta is added and returns to a boil sooner; the pasta cooks evenly and less starch crowds the water.

8. **Medium** Rumford's water boiled after about 2.5 hours. If the box held 8.5 kg of water starting at 15 °C, how much energy did the friction add (ignore losses)? What average power?

   Show answer

   $q = (8500)(4.18)(85) = 3.02 \times 10^6$ J; $P = 3.02 \times 10^6 / 9000$ s ≈ 336 W.

9. **Hard** You pour 200 g of water at 90 °C into a 300 g ceramic mug at 20 °C (c = 0.85 J/(g·°C)). Find the final temperature, ignoring losses.

   Show answer

   $(200)(4.18)(90 - T) = (300)(0.85)(T - 20)$ gives $T = 73.6$ °C. Warming the mug first keeps drinks hotter.

10. **Hard** Why is water's specific heat so much higher than oil's? Use the idea of hydrogen bonds.

    Show answer

    Much of the energy added to water goes into stretching and breaking hydrogen bonds between molecules rather than into making the molecules move faster, so more energy is needed per degree.

11. **Challenge** A family boils 4 L of water for pasta 3 times a week. Using Worked Example 1 and an electric stove that is 70% efficient, find the electrical energy per year in kWh (1 kWh = 3.6 MJ) and the cost at 15¢ per kWh.

    Show answer

    Per boil: $1.34/0.70 = 1.91$ MJ; per year: $1.91 \times 156 = 298$ MJ $= 82.8$ kWh; cost about $12.40.

COMMON MISTAKES

- Forgetting to convert minutes to seconds when calculating watts.
- Using the mass of the pot instead of the mass of the water in $q = mc\Delta T$.
- Adding oil to pasta water to stop sticking. It floats on top; stirring in the first minute is what works.
- Leaving heated oil unattended because it is “not boiling.”

> **Make it a game · Heat Math Duel.** Your parent calls out a mass of water and a temperature change. Calculate q with 4.18 joules per gram per degree Celsius, and say it aloud with units. Race through eight rounds. Then compare a pot of water to a pot of oil for the same heating and explain why. Tell how Rumford disproved the caloric theory.

2.3 Joseph Black, Latent Heat and the Steam Burn

OBJECTIVES

- Tell how Joseph Black discovered latent heat in Glasgow around 1761 by watching ice melt and water boil.
- Explain phase changes and calculate the energy of melting and boiling with q = mL, and explain why steam burns worse than boiling water.
- Record a heating curve from ice to boiling, and cook a steamed dinner.

> **Warm-up.** Put a thermometer in a glass packed with ice and a little water and set it on the counter. Read it every 5 minutes during the warm-up and the video. The ice is absorbing heat from the room. Is the temperature going up?

WATCH

Phase transitions in cooking

Harvard Online · 2:47

https://www.youtube.com/watch?v=FzYVBjGKSIY

> **WHEN TO WATCH**
> During session 1. Listen for what happens to the temperature while a substance is changing phase.

KEY TERMS

phase change

A change between solid, liquid and gas, such as melting, freezing, boiling or condensing.

latent heat

Heat absorbed or released during a phase change without any change in temperature.

heat of fusion

Energy needed to melt 1 g of a solid at its melting point. For ice, about 334 J/g.

heat of vaporization

Energy needed to turn 1 g of liquid into gas at its boiling point. For water, about 2,260 J/g.

condensation

Gas turning back into liquid, releasing its latent heat to whatever it touches.

CORE IDEAS

The story. Joseph Black, a Scottish physician and chemistry professor at Glasgow, puzzled over something everyone had seen and no one had explained. When snow thaws in spring, it does not all turn to water in an instant the moment the air rises above freezing; it melts slowly for days. Around 1761 he began careful measurements: if ice and water at the freezing point have the same temperature, why does the ice take so long to melt?

How they figured it out. Black set a flask of ice and a flask of the same mass of ice-cold water side by side in a warm room. The water warmed by several degrees in half an hour. The ice-water mixture stayed at the freezing point for about ten and a half hours until all the ice was gone. Both flasks were taking in heat from the room at about the same rate, so the ice had absorbed a great deal of heat without getting any warmer. Black called this hidden heat **latent heat**. He then showed that boiling works the same way: water at the boiling point needs much more heat to turn to steam. His student James Watt used the idea to design a far more efficient steam engine.

The kitchen science. During a phase change, added energy breaks the attractions between molecules (hydrogen bonds, for water) instead of making them move faster, so the temperature stays flat. Melting ice takes about 334 J per gram; boiling water away takes about 2,260 J per gram, almost seven times as much, and more than five times the energy needed to heat the same water from 0 to 100 °C. This is why a pot of boiling water stays at the boiling point however high you turn the burner (the extra heat only boils it away faster), and why food in boiling water can never get hotter than about 212 °F. It is also why **steam burns are so serious**: when steam touches your skin it condenses and releases all 2,260 J per gram into you, on top of the heat of the hot water itself. And it explains **steaming** as a cooking method: steam condensing on cool food delivers heat quickly and gently, without leaching flavor and nutrients into a pot of water.

Let's cook. You will steam fish fillets with ginger and green onions and steam broccoli alongside, then compare steamed broccoli with boiled. The skill is **steaming safely**: water below the basket, a lid on, and the lid lifted away from you so the steam escapes on the far side.

PICTURE STUDY



The Soup Kitchen (Die Armensuppe), Albert Anker, 1893 · Oil on canvas · Private collection

Image: Wikimedia Commons, public domain

Albert Anker painted the people of his Swiss village with great tenderness. Here soup is shared with those in need, the kind of charity Rumford organized in Munich a century earlier.

Look closely

- Find the pot. How can you tell the soup is hot?
- Follow the steam. What happens to it as it rises into the cooler air?
- Look at the faces of the people waiting. What do they tell you?
- Find the ladle and the bowls. How would the server keep from being burned?

Talk about it

1. A big pot of soup stays hot a long time. Use specific heat and latent heat to explain why.
2. Why is a lid on a pot of soup both a fuel saver and a burn danger?
3. Anker shows a meal given freely. How does feeding others connect with what you are learning to do?

Safety first. Steam carries far more heat than boiling water: open lids away from you, keep your face and hands out of the rising steam, and use mitts to lift a steamer basket. Never let a steamer boil dry. Cool a minor burn under cool running water for 10–20 minutes, not ice or butter; get medical help for blisters larger than a coin or any burn on the face. Fish must reach 145 °F (63 °C).

KITCHEN LAB

The Heating Curve and a Steamed Dinner

You will repeat Black's observation as a graph: heat ice slowly to boiling and record the temperature every 30 seconds. Then you will steam a dinner and compare steamed and boiled broccoli.

You will need

- A medium saucepan, ice and a digital scale
- An instant-read thermometer and a timer
- A large pot with a lid and a steamer basket (or a metal colander that fits)
- A heat-proof plate that fits in the steamer, or a sheet of parchment
- Oven mitts and tongs
- Your lab notebook

Steamed Ginger-Scallion Fish with Steamed Broccoli

Serves 4 · Prep 15 min · Cook 15 min

Ingredients

- 4 white fish fillets such as cod, haddock or tilapia, about 1 inch thick (1½ lb, 680 g total)
- ½ teaspoon salt
- 2-inch piece fresh ginger, cut into thin matchsticks
- 4 green onions, cut into 2-inch lengths and thinly sliced lengthwise
- 2 tablespoons soy sauce mixed with 1 tablespoon water and 1 teaspoon sugar
- 2 tablespoons vegetable oil
- 4 cups broccoli florets
- Cooked rice for serving

Method

1. Put 1½ inches of water in the large pot, set the steamer basket above it (the water must not touch the basket), cover and bring to a boil.

2. Pat the fish dry, season with salt, and lay it on the plate in one layer. Scatter half the ginger on top.
3. Lifting the lid away from you, set the plate in the steamer. Cover and steam 8–10 minutes, until the fish flakes and reads 145 °F (63 °C) in the thickest part.
4. Lift the plate out with mitts. Steam the broccoli in the basket 4–5 minutes until bright green and just tender.
5. Scatter the remaining ginger and the green onions over the fish and drizzle on the soy mixture. Heat the oil in a small pan until it shimmers, then carefully spoon it over the onions; it will sizzle. Serve with the broccoli and rice.
6. Let the pot cool before emptying it. Wash the plate, basket and pan.

Allergy check: Contains fish, soy and wheat (soy sauce). For wheat-free, use tamari labeled gluten-free. For a fish allergy, steam boneless chicken breast cut into thin slices instead, to 165 °F (about 12–15 minutes).

Steps

1. **Prediction.** Sketch what you think the graph of temperature against time will look like from ice at about −10 °C to boiling.
2. **Heating curve.** Put 300 g of ice cubes (straight from the freezer) in the saucepan with the thermometer. Heat on low, stirring gently, and record the temperature every 30 seconds until the water has boiled for 3 minutes. Note when the last ice disappears and when boiling begins.
3. **Graph.** Plot the data. Label the flat parts (melting, boiling) and the sloped parts.
4. **Calculate.** Use the length of the melting plateau and the slope of the water-heating part to estimate the burner's power two ways, and compare.
5. **Steamed vs. boiled.** Cook 1 cup of broccoli in boiling water and 1 cup in the steamer for the same 4 minutes. Compare color, texture and taste, and look at the color of the boiling water.
6. **Cook** the steamed fish dinner and serve it.
7. **Conclusion.** Explain the two plateaus with latent heat, and why steamed vegetables keep more color and flavor.
8. Clean up and dry the steamer.

Tips

- The temperature in the ice may read slightly below 0 °C at first if the ice came from a very cold freezer. That sloped start is part of the curve.
- Steaming fish on a plate keeps the juices; spoon them over the rice.
- Check the water level in a steamer every 10 minutes during longer steaming.

Check your work

- ☐ I can explain latent heat and calculate q = mL.
- ☐ I recorded and graphed a heating curve with two plateaus.
- ☐ I steamed food safely and explained why steam burns are so serious.

LAB NOTEBOOK

1. Draw your heating curve with labeled phases and plateaus.
2. Draw water molecules in ice, liquid water and steam, showing how far apart and how fast they are.
3. Compare boiled and steamed broccoli in a table: color, texture, taste, color of cooking water.

KEY FORMULAS

$$q = mL$$

$$L_f = 334 \text{ J/g} \qquad L_v = 2260 \text{ J/g}$$

From history. Joseph Black also discovered carbon dioxide, which he called “fixed air,” in the 1750s, by heating limestone and magnesia alba. His student James Watt, an instrument maker at the University of Glasgow, realized that the old Newcomen steam engine wasted most of its fuel reheating its cylinder, and invented the separate condenser in 1765.

WORKED EXAMPLES

Example 1. How much energy does it take to turn 100 g of ice at 0 °C into steam at 100 °C?

Show solution

1. Melt: $q_1 = (100\ \text{g})(334\ \text{J/g}) = 33{,}400\ \text{J}$.
2. Heat water: $q_2 = (100)(4.18)(100)\ \text{J} = 41{,}800\ \text{J}$.
3. Boil: $q_3 = (100\ \text{g})(2260\ \text{J/g}) = 226{,}000\ \text{J}$.
4. Total: $q = 33{,}400 + 41{,}800 + 226{,}000 = 301{,}200\ \text{J}$.

Answer: About 301,000 J (0.30 MJ). Three-quarters of it goes into boiling.

Example 2. Compare the heat delivered to skin by 1.0 g of boiling water and by 1.0 g of steam, each ending at 37 °C.

Show solution

1. Water: $q = (1.0)(4.18)(100 - 37)\ \text{J} = 263\ \text{J}$.
2. Steam: condensing 2260 J, then cooling 263 J: total 2523 J.
3. Ratio: $\dfrac{2523}{263} = 9.6$.

Answer: Steam delivers almost ten times as much heat per gram. Always lift a lid away from you.

Example 3. During steaming, a pot loses 120 g of water in 10 minutes. How much energy went into making that steam, and what average power is that?

Show solution

1. $q = (120\ \text{g})(2260\ \text{J/g}) = 271{,}200\ \text{J}$.
2. $P = \dfrac{271{,}200\ \text{J}}{600\ \text{s}} = 452\ \text{W}$.

Answer: About 271 kJ, or about 450 W of the burner's output going into steam.

Example 4. A cook drops 200 g of ice cubes into 800 g of hot soup at 80 °C to cool it quickly. Treating the soup as water, find the final temperature.

Show solution

1. Heat to melt the ice and warm its water: $(200)(334) + (200)(4.18)(T_f - 0)$.
2. Heat lost by the soup: $(800)(4.18)(80 - T_f)$.
3. $66{,}800 + 836\,T_f = 267{,}520 - 3344\,T_f \;\Rightarrow\; 4180\,T_f = 200{,}720 \;\Rightarrow\; T_f = 48\,^\circ\text{C}$.

Answer: About 48 °C (118 °F). Melting the ice did most of the cooling, which is why ice baths and ice wands chill food so quickly.

PRACTICE

1. Easy What happens to the temperature of ice water while the ice is melting?

   Show answer

   It stays at 0 °C (32 °F) until all the ice is melted.

2. Easy Find the energy to melt 50 g of ice at 0 °C.

   Show answer

   $(50)(334) = 16{,}700$ J

3. Easy Find the energy to boil away 50 g of water at 100 °C.

   Show answer

   $(50)(2260) = 113{,}000$ J

4. Medium Why does turning the burner to high not make boiling pasta water any hotter?

   Show answer

   Extra energy goes into turning water to steam (latent heat), so the temperature stays at the boiling point; it only boils away faster.

5. Medium In Black's experiment, the ice took about 21 times as long to melt as the water took to warm 8 °F (about 4.4 °C). Use this to estimate the latent heat of fusion in J/g.

   Show answer

   Heat to melt ≈ 21 × heat for 4.4 °C: $21 \times 4.18 \times 4.4 \approx 386$ J/g, in the neighborhood of the accepted 334 J/g.

6. **Medium** How much heat does 5 g of steam release when it condenses on your hand and cools to 37 °C?

   Show answer

   $5(2260) + 5(4.18)(63) = 11{,}300 + 1{,}317 = 12{,}600$ J

7. **Medium** Why do steamed vegetables usually keep more water-soluble vitamins than boiled ones?

   Show answer

   They do not sit in water, so vitamins such as vitamin C and folate are not leached out into cooking water that is poured away.

8. **Medium** What safe minimum internal temperature does fish need?

   Show answer

   145 °F (63 °C).

9. **Hard** How much ice at 0 °C must be added to 1,000 g of stock at 90 °C to bring it to 40 °C? Treat the stock as water.

   Show answer

   $m(334) + m(4.18)(40) = 1000(4.18)(50)$; $m = 209{,}000/501.2 = 417$ g.

10. **Hard** Sweating cools the body. If 100 g of sweat evaporates from skin (take L = 2,400 J/g at skin temperature), how much heat is removed?

    Show answer

    $(100)(2400) = 240{,}000$ J (240 kJ).

11. **Challenge** A pressure-cooker lid is opened too soon, releasing 10 g of steam onto a cook's arm. Compare the heat with spilling 10 g of 100 °C water, and explain why the injury differs.

    Show answer

    Steam: $10(2260) + 10(4.18)(63) = 25{,}200$ J; water: 2,630 J. About ten times the heat; steam also spreads over the skin and condenses there, so burns are deeper and larger.

COMMON MISTAKES

- Opening a pot lid toward your face.
- Thinking a rolling boil is "hotter" than a gentle boil. Both are at the boiling point.

- Letting a steamer boil dry, which can scorch the pot and start a fire.
- Putting ice or butter on a burn instead of cool running water.

> **Make it a game · Energy Rank.** Write on three cards: melt 100 grams of ice, heat 100 grams of water from 0 to 100 degrees Celsius, boil it all to steam. Rank them by energy from your gut, then calculate with the heats of fusion and vaporization. Closest ranking wins. Explain how latent heat makes steam burns worse. Tell Joseph Black's discovery.

2.4 Denis Papin's Digester: Pressure and the Boiling Point

OBJECTIVES

- Tell how Denis Papin built his steam digester in London in 1679 and added the first safety valve.
- Explain how air pressure sets the boiling point, why water boils cooler in the mountains and hotter in a pressure cooker, and estimate cooking-time changes.
- Cook dried beans by simmering or in a pressure cooker (with a parent present), and explain why beans must be boiled.

> **Warm-up.** Look up your town's altitude. Using the rule from Lesson 1.4, at what temperature does water boil in your kitchen? How might that change the time it takes to cook pasta or eggs compared with a kitchen at sea level?

WATCH

Water Boiling at Everest - Periodic Table of Videos

Periodic Videos · 9:28

https://www.youtube.com/watch?v=JTL4dj3Gx1o

> **WHEN TO WATCH**
> During session 1. Record the boiling point the team measures at each altitude, and then graph boiling point against altitude in your notebook.

BACKUP VIDEO

The Science Behind Pressure Cookers

America's Test Kitchen · 1:50

https://www.youtube.com/watch?v=wMEAl-uRnbg

After the main video. Watch how the pressure cooker raises the boiling point to about 250 °F.

KEY TERMS

pressure

Force per unit area. Air at sea level presses with about 14.7 pounds per square inch (psi), or 101.3 kilopascals (kPa): one atmosphere.

boiling point

The temperature at which a liquid's vapor pressure equals the pressure of the air above it, so bubbles of vapor can form throughout the liquid.

vapor pressure

The pressure of the vapor escaping from a liquid; it rises steeply with temperature.

pressure cooker

A sealed pot that traps steam, raising the pressure and therefore the boiling point to about 250 °F (121 °C).

safety valve

A valve that opens when pressure rises too high, letting steam escape before the vessel can burst. Papin invented it.

CORE IDEAS

The story. Denis Papin was a French physicist who worked in London with Robert Boyle, the great experimenter on air and pressure. In 1679 Papin showed the Royal Society a heavy iron pot with a tightly clamped lid that he called a *digester*. In it, bones softened and meat became tender far faster than in an open pot. In 1681 he published *A New Digester or Engine for Softening Bones*, and in 1682 he served the Royal Society a supper cooked in it; the diarist John Evelyn, who was there, wrote that even the bones of the beef and mutton were made as soft as cheese.

How they figured it out. Papin understood that sealing the pot kept the steam in, that the trapped steam pushed down on the water, and that water under higher pressure had to get hotter before it would boil. But sealed pots of boiling water can explode. Papin added a weighted lever that held a small valve closed until the pressure grew too great, then lifted to let steam out: the first **safety valve**. Every pressure cooker, boiler and water heater today has one.

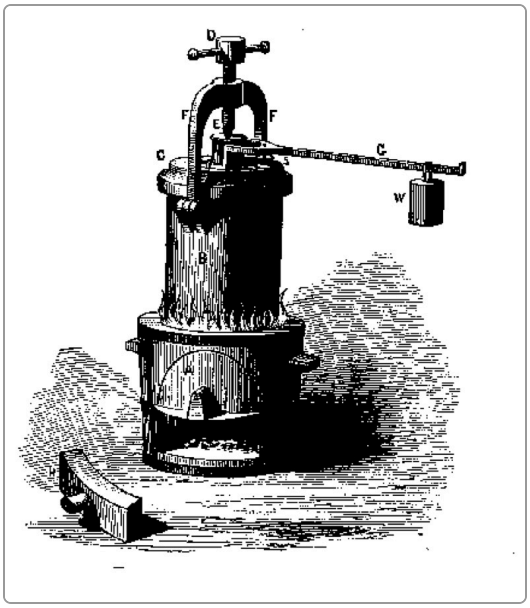
The kitchen science. Water boils when its **vapor pressure** equals the pressure of the air above it. At sea level that happens at 212 °F (100 °C). Higher up there is less air above you, so water boils at a lower temperature: about 1 °F lower per 500 feet, about 203 °F in Denver, about 160 °F on top of Mount Everest. Food in boiling water cooks

more slowly in the mountains, because it can never get hotter than the boiling water around it. A pressure cooker does the opposite. At about 15 psi above the outside air (roughly two atmospheres in all), water boils at about 250 °F (121 °C). A useful rule of thumb in food chemistry is that many cooking reactions roughly double in speed for every 10 °C rise, so 21 °C more heat can make tough foods cook three to four times faster.

Think it through. Dried beans are a good test. They must be cooked at a full boil: raw and undercooked kidney beans (and some other beans) contain a protein called phytohaemagglutinin that can cause severe stomach upset, and boiling destroys it. This is why dried beans should never be cooked only on the low setting of a slow cooker without boiling them first. Soaking lets water into the beans so they cook evenly and faster.

Let's cook. You will cook a pot of seasoned black beans, either simmered on the stove or in a pressure cooker with a parent present, and serve them with rice. The skill is **controlling a simmer** (small bubbles breaking gently) or, with the pressure cooker, **following its release instructions** exactly.

PICTURE STUDY



Papin's Digester, Engraving after Denis Papin, Late 17th century · Engraving · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Papin published drawings of his digester so others could build it. The heavy screw clamp holds the lid on against the pressure, and the weighted lever on top is the safety valve.

Look closely

- Find the screw clamp. Why must the lid be held on so strongly?
- Find the lever and its weight. What happens when the steam pushes up harder than the weight presses down?
- Find the furnace below. How would Papin control the heat?
- Compare this with a modern pressure cooker. Which parts are the same?

Talk about it

1. Moving the weight farther out on the lever would raise the pressure needed to open the valve. What would that do to the cooking temperature?
2. Why was it important that Papin published his design instead of keeping it secret?
3. Papin wanted cheap, nourishing food from bones that were usually thrown away. What does that tell you about his purpose?

> **Safety first.** Use a pressure cooker only with a parent present, following its manual: never overfill it (no more than half full for beans, which foam), check that the valve is clear, and never force the lid open; release pressure as the manual directs and open the lid away from you. Boil dried beans fully; never cook them only on a slow cooker's low setting from raw.

KITCHEN LAB

Find Your Boiling Point, Then Cook the Beans

You will measure your kitchen's boiling point and compare it with the altitude prediction, then cook dried black beans and record how cooking time depends on temperature.

You will need

- A calibrated instant-read thermometer
- A medium saucepan
- A large pot with a lid, or an electric or stovetop pressure cooker (used with a parent)
- A colander and a large bowl for soaking
- A digital scale
- Your lab notebook

Seasoned Black Beans

Serves 6 (about 6 cups) · Soak 8–24 hr · Simmer 1–1½ hr (or 10 min at pressure)

Ingredients

- 1 lb (450 g) dried black beans
- 2 tablespoons olive oil
- 1 onion, diced
- 1 green bell pepper, diced
- 4 cloves garlic, minced
- 2 teaspoons ground cumin and 1 teaspoon dried oregano
- 2 bay leaves
- 6 cups water (4 cups for a pressure cooker)
- 1½ teaspoons salt (add near the end), and 1 tablespoon lime juice or vinegar
- Cooked rice, chopped cilantro and lime wedges for serving

Method

1. Sort the beans on a tray, removing any stones or shriveled beans. Rinse them. Weigh them dry and record the mass.
2. Soak in a large bowl covered with 3 inches of water for 8–24 hours. Drain, weigh again and record.
3. In the pot, cook the onion and pepper in the oil over medium heat for 6 minutes, add the garlic, cumin and oregano and stir 1 minute.
4. **Stovetop:** add the beans, bay leaves and 6 cups water. Bring to a full boil and boil 10 minutes, then lower to a gentle simmer, partly covered, for 60–90 minutes, until creamy inside. Add water if needed to keep them covered.
5. **Pressure cooker (with a parent):** add the beans, bay leaves and 4 cups water (no more than half full). Lock the lid and cook 10 minutes at high pressure, then let the pressure release naturally for 15 minutes before releasing the rest as the manual directs.
6. Stir in the salt and lime juice, simmer 5 minutes more, remove the bay leaves, and taste. Serve over rice with cilantro and lime.
7. Cool leftovers quickly in shallow containers and refrigerate within 2 hours (they keep 4 days and freeze well). Wash the pot and its gasket.

Allergy check: Contains none of the nine major allergens. Beans are rich in fiber; serve a moderate first portion if your family is not used to them.

Steps

1. **Predict.** Use your altitude to predict your boiling point in °F and °C.
2. **Measure.** Boil 2 cups of water in the saucepan. With the probe in the middle of the water (not touching the pot), record the reading every 30 seconds for 3 minutes once at a rolling boil. Average the readings and apply your calibration correction from Lesson 1.4.
3. **Compare.** Find the percent difference between your measured and predicted boiling points. Check today's weather: a low-pressure storm lowers the boiling point slightly.
4. **Soaking data.** Find the percent mass increase of the beans after soaking.
5. **Cook and test.** Starting at 45 minutes of simmering (or right after the pressure is released), take out 3 beans every 10 minutes and press each

between your fingers; record when they are creamy all the way through.

6. **Analyze.** If your family has both methods, compare times; otherwise compare your time with the pressure-cooker time using the $2^{\Delta T/10}$ rule.
7. **Serve** the beans with rice and write a family rating.
8. Clean up: wash the pot; for a pressure cooker, remove and wash the gasket and check the valve.

Tips

- Salt and acid can slow softening if added at the very start in large amounts; adding them near the end is the safe habit.
- Very old dried beans may never soften fully. Buy from a store that sells a lot of them.
- Above about 3,000 ft, add extra simmering time and water.

Check your work

- ☐ I can explain how pressure sets the boiling point.
- ☐ I measured my kitchen's boiling point and compared it with a prediction.
- ☐ I cooked dried beans safely and explained why they must be boiled.

LAB NOTEBOOK

1. Draw a pressure cooker in cross-section, labeling the trapped steam, the higher pressure on the water, the 250 °F boiling point and the safety valve.
2. Graph boiling point against altitude from the video data and mark your own kitchen.
3. Record the soaking and cooking data and the recipe in your own words.

KEY FORMULAS

$$T_{\text{boil}}(^\circ\text{F}) \approx 212 - \frac{\text{altitude (ft)}}{500}$$

$$\text{rate ratio} \approx 2^{\Delta T/10\,^\circ\text{C}}$$

$$1\ \text{atm} = 14.7\ \text{psi} = 101.3\ \text{kPa}$$

From history. Papin also built a small model of a piston pushed by steam (about 1690) and later a steam-powered paddle boat. He died poor and nearly forgotten around 1712, but his digester, his safety valve and his piston are ancestors of the pressure cooker and the steam engine.

WORKED EXAMPLES

Example 1. Estimate the boiling point of water in Denver (5,280 ft) in °F and °C.

Show solution

1. $212 - \dfrac{5280}{500} = 212 - 10.6 = 201.4\ ^\circ\text{F}$.
2. $C = \frac{5}{9}(201.4 - 32) = 94.1\ ^\circ\text{C}$.

Answer: About 201 °F (94 °C). (Measured values are about 202–203 °F; the rule is an estimate.)

Example 2. A pressure cooker's gauge reads 15 psi above the outside air at sea level. Find the total pressure inside in psi and in atmospheres.

Show solution

1. $P = 14.7\ \text{psi} + 15\ \text{psi} = 29.7\ \text{psi}$.
2. $\dfrac{29.7\ \text{psi}}{14.7\ \text{psi/atm}} = 2.02\ \text{atm}$.

Answer: About 29.7 psi, or about 2 atmospheres, where water boils near 121 °C (250 °F).

Example 3. Using the rule that cooking reactions roughly double every 10 °C, estimate how much faster beans cook at 121 °C than at 100 °C. If they simmer in 90 minutes, about how long in the pressure cooker?

Show solution

1. Temperature rise: $\Delta T = 21\ ^\circ\text{C}$.
2. Rate ratio: $2^{21/10} = 2^{2.1} = 4.3$.
3. Time: $\dfrac{90\ \text{min}}{4.3} = 21\ \text{min}$.

Answer: About 4 times faster, roughly 20 minutes. Real pressure-cooker charts for soaked black beans give about 8–12 minutes at pressure plus time to come up to pressure and release, so the rule gives the right order of magnitude.

Example 4. At 7,500 ft, water boils at about 197 °F (92 °C). Estimate how much slower a food that cooks in 10 minutes at 100 °C will cook there.

Show solution

1. $\Delta T = 100 - 92 = 8\ ^\circ\text{C}$; $2^{8/10} = 1.74$.
2. $10\ \text{min} \times 1.74 = 17\ \text{min}$.

Answer: About 1.7 times as long, roughly 17 minutes. This is why high-altitude cooks add time to pasta, beans and eggs.

PRACTICE

1. Easy In what year did Papin show his digester to the Royal Society?

   Show answer

   1679.

2. Easy Convert 2 atm to psi.

   Show answer

   $2 \times 14.7 = 29.4\ \text{psi}$

3. Easy Estimate the boiling point of water at 2,500 ft.

   Show answer

   $212 - 5 = 207\ ^\circ\text{F}$

4. **Medium** Explain why water boils at a lower temperature on a mountain.

Show answer

There is less air above pressing down, so the water's vapor pressure equals the air pressure at a lower temperature.

5. **Medium** Why is the safety valve essential on a pressure cooker?

Show answer

If heat continues and steam cannot escape, the pressure keeps rising until the pot could burst; the valve lets steam out at a set pressure.

6. **Medium** Beans weigh 450 g dry and 990 g after soaking. Find the percent increase and the mass of water absorbed.

Show answer

540 g absorbed; $540/450 \times 100\% = 120\%$.

7. **Medium** Use the $2^{\Delta T/10}$ rule to estimate how much faster a reaction goes at 110 °C than at 100 °C.

Show answer

About 2 times faster.

8. **Medium** Why must dried kidney beans be boiled rather than only warmed in a slow cooker?

Show answer

They contain phytohaemagglutinin, which causes illness; boiling destroys it, but low temperatures may not.

9. **Hard** An egg takes 10 minutes to hard-cook at sea level. Estimate the time at 10,000 ft (boiling point about 194 °F).

Show answer

194 °F = 90 °C; $\Delta T = 10\ ^\circ\text{C}$, so about $2 \times 10 = 20$ min. (Real high-altitude cooks report noticeably longer times; the rule is approximate.)

10. Hard A pressure cooker's low setting is about 7 psi above the outside air. Estimate the total pressure in atm and say whether the cooking temperature will be higher or lower than on high (15 psi).

Show answer

$(14.7 + 7)/14.7 = 1.48$ atm; lower than high, about 110–115 °C.

11. Challenge Explain why food in a pressure cooker cooks faster even though it is not touching anything hotter than 121 °C, while food in a 350 °F oven (177 °C) cooks more slowly than in boiling water.

Show answer

Heat transfer depends on the medium as well as the temperature. Water and condensing steam transfer heat to food far more efficiently than dry air, and in the cooker they are at 121 °C. Hot air at 177 °C carries little heat per volume and transfers it slowly, and the food's surface is cooled by evaporation.

COMMON MISTAKES

- Filling a pressure cooker too full with beans, which foam and can clog the valve.
- Forcing the lid open before the pressure is fully released.
- Assuming recipe times written for sea level will work in the mountains.
- Not sorting dried beans; small stones are common.

> **Make it a game · Altitude Table.** Build a table from memory of boiling points at sea level, 5,000 feet and 10,000 feet, using the rule of about one degree Fahrenheit lost per 500 feet. Your parent names a city and altitude, and you predict the boiling point and the extra pressure-cooker time. Tell the safety valve story from Papin's 1679 digester.

2.5 Conduction, Convection and Radiation: Percy Spencer's Melted Candy Bar

OBJECTIVES

- Tell how Percy Spencer at Raytheon discovered microwave cooking in 1945.
- Explain conduction, convection and radiation in a kitchen, calculate a microwave's wavelength from its frequency, and use a simple conduction formula.
- Compare three ways of toasting bread, and roast a sheet-pan dinner that uses all three kinds of heat transfer.

> **Warm-up.** Hold your hand near (not on) a warm stovetop, a toaster, and above a pot of steaming water, each from a safe distance. Which heat do you feel from the side? From above? What might be carrying the heat to your hand each time?

WATCH

GCSE Physics - Conduction, Convection & Radiation | How Heat Energy is Transferred (2027/28 exams)

Cognito · 4:30

https://www.youtube.com/watch?v=rUnABMRPzvg

> **WHEN TO WATCH**
> During session 1. For each kind of heat transfer, write one example from your kitchen.

BACKUP VIDEO

The Microwave: Where did it come from? | Stuff of Genius

HowStuffWorks · 2:03

https://www.youtube.com/watch?v=JcQ2ugJ2n0g

After the story. A short, lively history of Spencer's discovery and the first microwave oven.

KEY TERMS

conduction

Heat moving through a material, or between materials that touch, as faster-vibrating particles bump slower ones. A pan heats an egg by conduction.

convection

Heat carried by a moving fluid, such as boiling water or hot oven air. A fan oven increases convection.

radiation

Heat carried by electromagnetic waves, such as infrared from glowing coals or a broiler, which needs no contact or air.

thermal conductivity

How easily a material conducts heat. Copper and aluminum are high; wood and air are low.

microwaves

Electromagnetic waves (in ovens, 2.45 gigahertz, about 12 cm long) that make water molecules in food twist back and forth and heat up.

CORE IDEAS

The story. Percy Spencer left school before finishing grammar school, taught himself electronics, and became one of the best engineers at the Raytheon company in Massachusetts, where during World War II he found ways to mass-produce the magnetron tubes that powered radar. In 1945, working near an operating magnetron, he noticed that a candy bar in his pocket had melted.

How they figured it out. Spencer was not the first to feel warmth near radar equipment, but he was curious enough to test it. He set popcorn kernels near the tube, and they popped. He tried an egg, which heated so fast from the inside that it burst. Raytheon filed a patent on cooking with microwaves in 1945 (granted in 1950), and in 1947 sold the first commercial microwave oven, the Radarange: nearly six feet tall and weighing about 750 pounds. Countertop home models became common in the 1970s.

The kitchen science. Every cooking method moves heat in three ways. **Conduction** passes heat through solids and between things that touch: a hot pan into a pancake, the outside of a roast to its center. Metals conduct well, wood and air poorly, which is why a wooden spoon handle stays cool. **Convection** carries heat in moving fluids: rolling boiling water, hot oil, or oven air (a convection oven's fan speeds it up and browns food faster). **Radiation** carries heat as electromagnetic waves: infrared from glowing broiler elements and coals, which browns the surface it can "see." Microwaves are a special case of radiation. At 2.45 GHz they reach a centimeter or two into food and make polar water molecules rotate back and forth billions of times

a second, heating the food from within that depth; the rest of the food heats by conduction, which is why microwaved food needs stirring and standing time.

Think it through. Almost every real dish uses all three. On a sheet pan in a hot oven, the pan conducts heat into the bottom of the vegetables, hot air convects around them, and the oven walls and heating element radiate onto their tops. Dark pans absorb more radiation and brown food faster; crowded pans trap steam and lose the browning.

Let's cook. You will roast a sheet-pan dinner of sausage, potatoes, peppers and onions. The skill is **arranging a sheet pan:** pieces cut to cook in the same time, spread in one layer with space between them, and turned once.

PICTURE STUDY



The Milkmaid, Johannes Vermeer, c. 1657–1658 · Oil on canvas · Rijksmuseum, Amsterdam

Image: Wikimedia Commons, public domain

Vermeer's kitchen maid is preparing a meal, probably a bread pudding or porridge from stale bread and milk. Light, heat and food are everywhere in this small, quiet room.

Look closely

- Find the window. What kind of energy is coming through it?
- Find the small wooden box on the floor at the right. It is a foot warmer that held a pot of hot coals. How did it warm a person's feet?
- Find the bread, the jug and the bowl. Which ones would feel warm if they had just come from the fire?
- Look at the stream of milk. Why is she pouring so slowly?

Talk about it

1. Name the kinds of heat transfer you can find or imagine in this picture: the foot warmer, the sunlight, a pot of milk heating over a fire.
2. Why was a foot warmer's heat mostly radiation and convection rather than conduction?
3. Vermeer made ordinary work look dignified and beautiful. What ordinary kitchen work do you do that deserves care?

Safety first. The broiler and a 425 °F oven radiate intense heat: use long mitts, pull the rack out rather than reaching in, and keep towels away from the oven door. Never run a microwave empty or with metal inside, and stir and let microwaved food stand, because hot spots can scald. Sausage must reach 160 °F (71 °C) (165 °F for poultry sausage).

KITCHEN LAB

Three Ways to Toast, and a Sheet-Pan Dinner

Which kind of heat transfer browns bread fastest? You will toast identical slices by conduction (a dry skillet), convection (a hot oven) and radiation (the broiler), then cook a sheet-pan dinner that uses all three.

You will need

- A dry skillet, a rimmed sheet pan and the oven broiler
- Three slices of the same bread
- A timer and a thermometer
- A chef's knife and cutting board
- Long oven mitts and tongs
- Your lab notebook

Sheet-Pan Sausage, Potatoes and Peppers

Serves 4–6 · Prep 20 min · Roast 35–40 min

Ingredients

- 1½ lb (680 g) Yukon Gold or red potatoes, cut into 1-inch pieces
- 2 bell peppers, cut into 1½-inch pieces
- 1 large red onion, cut into wedges
- 3 tablespoons olive oil
- 1 teaspoon salt, ½ teaspoon pepper, 1 teaspoon dried Italian seasoning, 1 teaspoon smoked or sweet paprika
- 1¼ lb (570 g) fresh Italian sausage links (pork, chicken or turkey)
- Chopped parsley for serving

Method

1. Heat the oven to 425 °F (220 °C) with a rack in the middle. Line the sheet pan with foil if you like.
2. Toss the potatoes with 2 tablespoons oil, half the salt, pepper and seasonings, and spread them on the pan. Roast 15 minutes.

3. Toss the peppers and onion with the remaining oil and seasonings. Add them to the pan along with the sausages, spaced apart, all in one layer.
4. Roast 20–25 minutes, turning the sausages and stirring the vegetables halfway, until the potatoes are browned and tender and the sausages read 160 °F (71 °C), or 165 °F (74 °C) for poultry sausage.
5. Sprinkle with parsley and serve. Refrigerate leftovers within 2 hours.
6. Let the pan cool before washing it; wash the board used for raw sausage with hot soapy water.

Allergy check: Most sausages contain none of the major allergens, but some contain milk, soy or wheat fillers: read the label. For a meatless version, use 2 cans of drained chickpeas, added with the peppers.

Steps

1. **Prediction.** Rank the three toasting methods from fastest to slowest and say why.
2. **Conduction.** Heat the dry skillet over medium for 3 minutes. Toast a slice, flipping once, timing until both sides are golden.
3. **Convection.** Toast a slice on a rack in a 425 °F oven, turning once, until golden; time it.
4. **Radiation.** Toast a slice 4 inches under the broiler, watching constantly and turning once; time it.
5. **Compare.** Photograph or sketch the three slices. Which browned evenly? Which dried out inside? Which side browned in each?
6. **Cook** the sheet-pan dinner. Halfway through, look at which sides of the potatoes are browning, and explain which kind of heat did it.
7. **Conclusion.** Explain your toast results with conduction, convection and radiation.
8. Clean up: turn off the broiler first, cool and wash the pans.

Tips

- Leave space between pieces on a sheet pan. Crowded vegetables steam instead of browning.
- Under the broiler, food can go from golden to burnt in 30 seconds. Never walk away.

- Cut potatoes smaller than peppers: dense potatoes need more time for heat to conduct to their centers.

Check your work

- ☐ I can name and explain conduction, convection and radiation with kitchen examples.
- ☐ I can calculate a microwave's wavelength and use the conduction formula.
- ☐ I compared three toasting methods and roasted a sheet-pan dinner safely.

LAB NOTEBOOK

1. Draw an oven with a sheet pan inside and arrows showing conduction, convection and radiation, each in a different color.
2. Record the toast experiment in a table: method, time, appearance, texture.
3. Write the sheet-pan recipe in your own words with one change you would make.

KEY FORMULAS

$$\lambda = \frac{c}{f}$$

$$\frac{Q}{t} = \frac{kA\,\Delta T}{d}$$

From history. The Radarange was first used in restaurants, railroad dining cars and ships. In 1967 Amana, a Raytheon company, introduced a countertop microwave for homes that cost about $495, and by the late 1980s most American kitchens had one.

WORKED EXAMPLES

Example 1. Microwave ovens use a frequency of 2.45 GHz (2.45×10^9 Hz). Find the wavelength ($c = 3.00 \times 10^8$ m/s).

Show solution

1. $\lambda = \dfrac{3.00 \times 10^8 \text{ m/s}}{2.45 \times 10^9 \text{ s}^{-1}} = 0.122 \text{ m} = 12.2 \text{ cm}.$

Answer: About 12 cm. That is why a microwave oven's cold and hot spots are several centimeters apart, and why most ovens have a turntable.

Example 2. Heat flows through the 3.0-mm aluminum base of a pan (k = 205 W/(m·K), area 0.030 m^2). The bottom is 220 °C and the inside surface 200 °C. Find the rate of heat flow.

Show solution

1. $\dfrac{Q}{t} = \dfrac{(205)(0.030)(20)}{0.0030}\ \text{W} = 41{,}000\ \text{W}.$

Answer: About 41 kW. A burner cannot supply that much, so in practice the temperature difference across an aluminum base is tiny: aluminum spreads heat evenly.

Example 3. A 2,000-W burner pushes heat through a 3.0-mm pan base of area 0.030 m^2. Find the temperature difference across the base if it is stainless steel (k = 16 W/(m·K)) and if it is aluminum (k = 205 W/(m·K)).

Show solution

1. Rearrange: $\Delta T = \dfrac{(Q/t)\,d}{kA}$.
2. Steel: $\Delta T = \dfrac{(2000)(0.0030)}{(16)(0.030)} = 12.5\ ^\circ\text{C}.$
3. Aluminum: $\Delta T = \dfrac{(2000)(0.0030)}{(205)(0.030)} = 0.98\ ^\circ\text{C}.$

Answer: About 12.5 °C across steel and only about 1 °C across aluminum. Steel holds hot spots over the flame; that is why good stainless pans have an aluminum or copper core.

Example 4. A 1,100-W microwave heats 400 g of soup from 5 °C to 70 °C in 3.0 minutes. What fraction of the oven's rated power reached the soup (treat soup as water)?

Show solution

1. $q = (400)(4.18)(65)\ \text{J} = 108{,}700\ \text{J}$.
2. $P = \dfrac{108{,}700\ \text{J}}{180\ \text{s}} = 604\ \text{W}$.
3. $\dfrac{604}{1100} = 0.55$.

Answer: About 55%. The rest goes to the container, the air, and losses in the magnetron.

PRACTICE

1. Easy Name the kind of heat transfer: (a) a steak on a hot grill grate, (b) a cake in a convection oven, (c) a marshmallow beside (not over) a campfire.

   Show answer

   (a) conduction; (b) convection; (c) radiation.

2. Easy In what year did Percy Spencer notice his melted candy bar?

   Show answer

   1945.

3. Easy Why does a wooden spoon handle stay cool in hot soup?

   Show answer

   Wood is a poor conductor of heat.

4. Medium A Wi-Fi router also uses 2.4 GHz. Find the wavelength of a 2.40-GHz wave.

   Show answer

   $3.00 \times 10^{8} / 2.40 \times 10^{9} = 0.125\ \text{m} = 12.5\ \text{cm}$

5. Medium Why does food in a microwave heat unevenly, and what two things help?

Show answer

Microwaves form hot and cold spots and penetrate only a centimeter or two; stirring (or a turntable) and standing time let conduction even out the heat.

6. Medium Why do vegetables brown faster on a dark pan than a shiny one?

Show answer

Dark surfaces absorb more of the oven's radiant heat, so the pan gets hotter and conducts more heat into the food.

7. Medium A 1,000-W microwave delivers 60% of its power to 300 g of water at 20 °C. How long to reach 90 °C?

Show answer

$q = (300)(4.18)(70) = 87{,}780$ J; $t = 87{,}780/600 = 146$ s.

8. Medium Why does a convection oven usually cook about 25 °F "hotter" than a regular oven at the same setting?

Show answer

The fan moves hot air faster, sweeping away the cooler air layer around the food, so heat transfers faster.

9. Hard Using Q/t = kAΔT/d, by what factor does heat flow change if a pan's base is made twice as thick?

Show answer

It halves (d doubles), if the temperature difference stays the same.

10. Hard Copper's thermal conductivity is about 400 W/(m·K). For the pan in Worked Example 3, find the temperature difference across a 3.0-mm copper base at 2,000 W.

Show answer

$\Delta T = (2000)(0.0030)/(400)(0.030) = 0.5\ ^\circ\text{C}$

11. **Challenge** Explain why a whole roast cooked in a microwave can be overcooked at the edges and raw in the middle, while a cup of water heats evenly.

Show answer

Microwaves only penetrate 1–2 cm, so the outer layer of a thick roast heats directly while the center depends on slow conduction through meat; water heats through its depth and also mixes by convection.

COMMON MISTAKES

- Crowding a sheet pan, so food steams instead of roasting.
- Thinking microwaves cook food “from the inside out.” They heat the outer 1–2 cm; the center is reached by conduction.
- Walking away from the broiler.
- Assuming a thin, cheap pan heats evenly; thin steel creates hot spots.

Make it a game · Three Ways Hunt. Set a three-minute timer and find a kitchen example of conduction, convection and radiation, and one example that combines two. Explain each in a sentence. Then compute a microwave's wavelength from 2.45 gigahertz using speed of light divided by frequency. Tell how Percy Spencer's candy bar led to the microwave oven.

Scripture. “And he looked, and, behold, there was a cake baken on the coals, and a cruse of water at his head.” (1 Kings 19:6, KJV)

Elijah’s bread was baked on coals by conduction and radiation, the oldest oven in the world, and given to a weary prophet by God’s care.

UNIT 2

Water and Heat

Almost every food is mostly water, and almost every recipe heats or cools it. This unit is about the molecule at the center of cooking and the energy that changes it. You will learn why water dissolves sugar and salt so well, why it takes so much energy to heat and even more to boil, why steam burns are so dangerous, why water boils cooler in the mountains and hotter in a pressure cooker, and how heat moves into food by conduction, convection and radiation.

The stories run from Cavendish's balance and Count Rumford's cannon to Joseph Black's melting ice, Denis Papin's digester and Percy Spencer's melted candy bar. The labs are real measurements: solubility, burner power, a heating curve, your own boiling point and a toasting experiment. The recipes are lemonade, pasta, steamed fish, black beans and a sheet-pan dinner. Along the way you will use $q = mc\Delta T$, $q = mL$ and the conduction formula with units in every line.

PREREQUISITES

- Unit 1: measuring by mass, calibrated thermometer, °F ↔ °C conversions, lab report format
- Algebra: solving a linear equation for an unknown, working with scientific notation
- Comfortable using the stove and oven with a parent at home

MASTERY CHECKLIST

- ☐ I can explain water's polarity and hydrogen bonds and use them to explain dissolving, specific heat and boiling.
- ☐ I can calculate heat with $q = mc\Delta T$ and $q = mL$, and power with $P = q/t$.
- ☐ I can explain latent heat, read a heating curve, and explain why steam burns are severe.
- ☐ I can explain how pressure and altitude set the boiling point and how a pressure cooker works.
- ☐ I can explain conduction, convection and radiation (including microwaves) with kitchen examples.
- ☐ I cooked pasta, steamed fish, beans and a sheet-pan dinner safely and recorded the labs.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **USDA FSIS: High Altitude Cooking and Food Safety**: Free on the USDA Food Safety and Inspection Service website (fsis.usda.gov). How altitude changes boiling points and cooking times. For Lesson 2.4.
- **A pressure cooker (stovetop or electric)**: Optional. Lesson 2.4 works by simmering; a pressure cooker shortens the beans to minutes and makes the boiling-point science concrete. Always used with a parent present.
- **A steamer basket**: Inexpensive and useful all year. A metal colander set over a pot with a lid works for Lesson 2.3.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

2.1	**Water: The Molecule That Cooks**	3 sessions of 50–90 minutes
2.2	**Count Rumford and Specific Heat**	3 sessions of 50–90 minutes
2.3	**Joseph Black, Latent Heat and the Steam Burn**	3 sessions of 50–90 minutes
2.4	**Denis Papin's Digester: Pressure and the Boiling Point**	3 sessions of 50–90 minutes (plus overnight soaking)
2.5	**Conduction, Convection and Radiation: Percy Spencer's Melted Candy Bar**	3 sessions of 50–90 minutes

Unit 2 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **5 pts**
   Explain what Cavendish and Lavoisier showed about water in the 1780s.

2. **6 pts**

   Describe water’s polarity and hydrogen bonding, and use them to explain why sugar dissolves well but oil does not.

3. **6 pts**

   Find the mass percent of a syrup made with 300 g sugar and 200 g water.

4. **6 pts**

   How much energy heats 3.0 kg of water from 18 °C to 100 °C?

5. **6 pts**

   A burner heats 1,500 g of water from 20 °C to 70 °C in 8.0 minutes. Find the power delivered to the water.

6. **6 pts**

   Describe Rumford’s cannon-boring experiment and what it showed.

7. **7 pts**

   500 g of pasta at 20 °C ($c = 1.8$ J/(g·°C)) is added to 3,000 g of water at 100 °C. Find the temperature after mixing, ignoring the burner.

8. **7 pts**

   Find the total energy to turn 200 g of ice at 0 °C into steam at 100 °C.

9. **7 pts**

   Explain with numbers why steam at 100 °C causes a worse burn than water at 100 °C.

10. **6 pts**

    What did Joseph Black observe about ice and water in a warm room, and what did he conclude?

11. **6 pts**

    Estimate the boiling point of water at 8,000 ft in °F and °C. Will pasta cook faster or slower there?

12. **7 pts**

A pressure cooker raises the boiling point to 121 °C. Using the doubling-per-10 °C rule, estimate how long a stew that needs 2 hours at 100 °C would take.

13. **5 pts**

Why is Papin's safety valve important, and how does it work?

14. **6 pts**

Find the wavelength of 2.45-GHz microwaves and explain how they heat food.

15. **4 pts**

Name the main kind of heat transfer in each: a pancake on a griddle; potatoes in boiling water; toast under a broiler.

16. **10 pts**

Short essay (5–7 sentences): Explain to a younger cook why a pot of boiling water never gets hotter than its boiling point, why it boils sooner with the lid on, why a big pot cooks pasta better, and how to open the lid safely. Use the words specific heat, latent heat and steam.

ANSWER KEY

1. Water is not an element but a compound of hydrogen and oxygen: Cavendish formed water by burning hydrogen in air (1781); Lavoisier decomposed and recombined it and named hydrogen (1783).
2. Oxygen pulls shared electrons, leaving the oxygen end slightly negative and the hydrogens slightly positive; neighboring molecules attract by hydrogen bonds. Sugar's –OH groups hydrogen-bond with water, so it dissolves; nonpolar oil cannot, and water squeezes it out.
3. $300/500 = 60\%$
4. $(3000)(4.18)(82) = 1.03 \times 10^6$ J
5. $q = (1500)(4.18)(50) = 313{,}500$ J; $P = 313{,}500/480 = 653$ W.
6. A blunt borer turned against a cannon in a box of water, driven by horses, boiled the water in about 2.5 hours with no fire. The heat seemed unlimited as long as work continued, so heat is a form of motion, not a fluid (caloric).
7. $(3000)(4.18)(100 - T) = (500)(1.8)(T - 20)$; $1{,}254{,}000 + 18{,}000 = 13{,}440\,T$, $T = 94.6\ ^\circ\text{C}$.
8. $200(334) + 200(4.18)(100) + 200(2260) = 66{,}800 + 83{,}600 + 452{,}000 = 602{,}400$ J
9. Each gram of steam releases 2,260 J as it condenses, then about 263 J cooling to body temperature (total about 2,520 J), compared with about 263 J for water: nearly ten times the heat.
10. Ice-cold water warmed several degrees in half an hour, while the same mass of ice stayed at the freezing point for about ten and a half hours as it melted, so melting absorbs a large amount of heat without changing temperature: latent heat.
11. $212 - 16 = 196\ ^\circ\text{F} \approx 91\ ^\circ\text{C}$; slower, because the water is cooler.
12. $2^{2.1} = 4.3$; $120\ \text{min}/4.3 \approx 28$ min.
13. It keeps the pressure from rising high enough to burst the vessel: a weight (or spring) holds a small valve shut until the steam pressure pushes it open and lets steam escape.
14. $\lambda = 3.00 \times 10^8 / 2.45 \times 10^9 = 0.122$ m. They make polar water molecules rotate back and forth rapidly in the outer 1–2 cm of food; the rest heats by conduction.
15. Conduction; convection; radiation.
16. Answers vary. Full credit for: extra energy goes into latent heat of vaporization so the temperature stays at the boiling point; the lid traps hot vapor and reduces

heat loss; a large mass of water stores more heat (high specific heat) so it drops less when pasta goes in; steam releases latent heat when it condenses, so lift the lid away from you.

UNIT PROJECT: THE FAMILY ENERGY NOTEBOOK

Choose three dishes your family cooks often (for example, pasta, rice and soup). For each, measure the mass of water used, the starting and final temperatures, and the time on the burner, and calculate the energy that went into the water and the power delivered.

Then test one change that could save time or energy for one of the dishes (a lid, less water, a smaller burner after boiling, a pressure cooker, or a microwave) with two trials each way. Write a two-page report with your data, calculations, a graph and a recommendation for your family, and cook the improved dish for a family meal.

LOOK FOR	WHAT IT MEANS
Measurements	Masses, temperatures and times recorded honestly with units; thermometer calibration applied.
Calculations	$q = mc\Delta T$, $q = mL$ and $P = q/t$ used correctly, with every step and unit shown.
Fair test	One change tested at a time, with two trials each way and other conditions controlled.
Recommendation	A clear, practical recommendation supported by the data, including any limits or surprises.
Safety and cleanup	Hot pots, steam and lids handled safely; kitchen clean after each trial.

UNIT 3

Carbohydrates

Carbohydrates are the sugars, starches and fibers that give us most of our food energy and much of the texture of our food. In this unit you will meet them from the smallest to the largest: the simple sugars and their sweetness, the sugars transformed by heat into caramel, the starch chains that swell and thicken a sauce, the same chains slowly lining up again in a stale loaf, and the fibers that our enzymes cannot digest at all.

The stories follow Marggraf's beet crystals, Milton Hershey's caramel kettles, Thomas Kingsford's corn starch, Boussingault's sealed loaf and William Beaumont's window into a living stomach. The labs measure Brix, candy stages, line spread, bread firmness and gel strength, and the recipes are a sorbet designed by calculation, caramel sauce, stovetop mac and cheese, panzanella from day-old bread and a fiber-rich baked oatmeal.

PREREQUISITES

- Unit 2: water's polarity and hydrogen bonds; q = mcΔT and latent heat
- Solving linear equations and working with percentages
- Comfort at the stove with a parent at home; a parent present for the hot-sugar lab

MASTERY CHECKLIST

- ☐ I can name and describe monosaccharides, disaccharides and polysaccharides and explain hydrolysis.
- ☐ I can calculate Brix and design a recipe to a target sugar concentration.
- ☐ I can explain the candy stages, boiling-point elevation and caramelization, and handle hot sugar safely.
- ☐ I can describe amylose and amylopectin and explain gelatinization and retrogradation.
- ☐ I can explain how carbohydrates are digested and what soluble and insoluble fiber do.
- ☐ I can calculate nutrient amounts per serving and %DV from ingredient labels.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FDA: How to Understand and Use the Nutrition Facts Label**: Free. Explains Daily Values, including the 28 g Daily Value for fiber used in Lesson 3.5.
- **A candy thermometer that clips to the pan**: Optional. An instant-read thermometer works for Lesson 3.2 if it reads above 350 °F, but a clip-on thermometer frees your hands.
- **A refractometer (Brix meter)**: Optional and inexpensive. Lets you measure the Brix of juices and sorbet bases directly instead of calculating them.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

3.1 Sugars, Sweetness and Brix: Marggraf's Beet

3 sessions of 50–90 minutes (plus freezing time)

3.2 Caramelization and the Candy Stages: Milton Hershey's Caramels

3 sessions of 50–90 minutes

3.3 Starch and Gelatinization: Thomas Kingsford's Cornstarch

3 sessions of 50–90 minutes

3.4 Retrogradation: Boussingault and the Stale Loaf

3 sessions of 50–90 minutes

3.5 Fiber and Digestion: Beaumont's Window into the Stomach

3 sessions of 50–90 minutes

Unit 3 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **5 pts**
   Name the monosaccharides that make up sucrose, lactose and maltose.

2. **6 pts**
   A sorbet base contains 600 g fruit purée at 9% sugar and 160 g sugar, with 140 g water. Find its Brix.

3. **7 pts**
   How much sugar must be added to 800 g of a 15 °Bx juice to reach 25 °Bx?

4. **6 pts**
   Explain why sugar makes sorbet softer.

5. **5 pts**
   What did Marggraf discover in 1747, and why did it matter?

6. **7 pts**

   A syrup of 400 g sugar and 150 g water is boiled to the hard-crack stage (99% sugar). How much water must evaporate, and how much energy does that take (L = 2,260 J/g)?

7. **6 pts**

   Distinguish caramelization from the Maillard reaction, and say which mostly browns a milk caramel.

8. **5 pts**

   A fudge recipe says 238 °F at sea level; water boils at 203 °F in your kitchen. What temperature should you cook to?

9. **6 pts**

   Describe gelatinization, with temperatures.

10. **6 pts**

    A gravy uses 24 g flour (72% starch) in 600 g of total liquid. Find its starch percentage, and the cornstarch (98% starch) needed for the same starch content.

11. **6 pts**

    Why does a roux or slurry prevent lumps?

12. **7 pts**

    Describe Boussingault's 1852 experiment and its conclusion.

13. **6 pts**

    A bread cube compresses 42% fresh, 33% after 3 days on the counter and 18% after 3 days in the refrigerator. Find each average firming rate and their ratio.

14. **6 pts**

    What did Beaumont learn from Alexis St. Martin, and what ethical lesson do doctors draw from the case today?

15. **6 pts**

    A recipe has 52 g of fiber and serves 8. Find fiber per serving and %DV (DV = 28 g).

16. **10 pts**

Short essay (5–7 sentences): Follow a slice of bread from the oven to three days later to its digestion in the body. Use the words gelatinization, retrogradation, amylase and fiber.

ANSWER KEY

1. Sucrose: glucose + fructose. Lactose: glucose + galactose. Maltose: glucose + glucose.
2. Sugar $54 + 160 = 214$ g; total 900 g; $214/900 \times 100 = 23.8$ °Bx.
3. $(120 + x)/(800 + x) = 0.25 \Rightarrow 0.75x = 80 \Rightarrow x = 107$ g
4. Dissolved sugar lowers the freezing point, so some water stays liquid at freezer temperature and ice crystals stay smaller and separated.
5. That beets contain sucrose identical to cane sugar; it led to beet-sugar factories (Achard, 1801) and cheaper sugar in Europe.
6. Final mass $400/0.99 = 404$ g; evaporate 146 g; energy $146 \times 2260 = 330{,}000$ J.
7. Caramelization: sugar alone, about 320 °F and up. Maillard: sugars with amino acids, at lower temperatures. Milk caramels brown largely by the Maillard reaction.
8. $238 - 9 = 229$ °F
9. Heated in water, starch granules absorb water and swell from about 140–150 °F, leak amylose and burst near boiling, and the chains tangle with water to thicken the liquid.
10. $17.3/624 = 2.8\%$; $17.3/0.98 = 17.6$ g.
11. It separates the starch granules (coated with fat or suspended in cold liquid) so they swell individually instead of forming gelatinized clumps around dry centers.
12. He sealed bread so it could not dry, found it staled while keeping almost the same mass, and that heating made it soft again; staling is a reversible change in the bread (starch retrogradation), not drying.
13. Counter 3 points/day; fridge 8 points/day; ratio about 2.7.
14. That digestion is a chemical process carried out by gastric juice, and how long foods take to digest. Research on people requires their free, informed consent.
15. 6.5 g; 23%.
16. Answers vary. Full credit for: starch gelatinized during baking; amylose and then amylopectin retrograde as bread cools and ages, faster in the refrigerator, reversed by reheating; amylase in saliva and from the pancreas breaks starch into maltose and then glucose; whole-grain bread's fiber is not digested by our enzymes but adds bulk and helps satiety.

UNIT PROJECT: THE FAMILY CARBOHYDRATE NOTEBOOK

Choose one family favorite that depends on carbohydrate chemistry: a pudding, a gravy, a jam, a candy, a bread or a breakfast. Explain the carbohydrate science in it in a one-page illustrated report (which sugars or starches are present, what heat and water do to them, and what happens when it is stored).

Then run a controlled experiment on one variable of the recipe (sugar amount, thickener type or amount, storage temperature or cooking temperature), with at least two trials of each treatment and a measurement such as Brix, line spread, compression or a ranked taste panel. Write it up as a full lab report and serve the best version to your family.

LOOK FOR	WHAT IT MEANS
Science explanation	Correctly explains the sugars, starch or fiber in the dish and the changes caused by heat, water and storage.
Experimental design	One variable changed, others controlled, at least two trials each.
Measurement and calculation	A real measurement with units; correct Brix, percentage or rate calculations.
Safety	Hot sugar, starch sauces and ovens handled safely with a parent present where needed.
Honest conclusion	Conclusion follows from the data, including surprises and sources of error.

3.1 Sugars, Sweetness and Brix: Marggraf's Beet

OBJECTIVES

- Tell how Andreas Marggraf found cane sugar in beets in 1747 and how Franz Achard built the first beet-sugar factory in 1801.
- Name the common monosaccharides and disaccharides, explain hydrolysis and invert sugar, and compare relative sweetness.
- Calculate degrees Brix and use them to design a scoopable sorbet.

> **Warm-up.** Taste (with clean spoons) a pinch of table sugar, a drop of honey, a slice of apple and a cracker held in your mouth for a minute. Rank them from sweetest to least sweet. Which one became sweeter the longer you held it?

WATCH

Food molecules: fats, carbohydrates, and proteins

Harvard Online · 8:28

https://www.youtube.com/watch?v=RVc02SAVUMI

> **WHEN TO WATCH**
> During session 1. Pause at the slides on sugars and starches and copy the structures of glucose, fructose and sucrose.

BACKUP VIDEO

Disaccharides - Sucrose, Maltose, Lactose - Carbohydrates

The Organic Chemistry Tutor · 5:30

https://www.youtube.com/watch?v=eMD-gGsuGRc

During the worked examples. A step-by-step chalkboard explanation of how two monosaccharides join into a disaccharide and release water.

KEY TERMS

carbohydrate

A molecule of carbon, hydrogen and oxygen, from simple sugars to starch and fiber; general formula roughly $(CH_2O)_n$.

monosaccharide

A single sugar unit, such as glucose, fructose or galactose (all $C_6H_{12}O_6$).

disaccharide

Two sugar units joined by a glycosidic bond, such as sucrose (glucose + fructose), lactose (glucose + galactose) and maltose (glucose + glucose).

degrees Brix (°Bx)

The percentage of dissolved sugar by mass in a liquid: 1 °Bx = 1 g of sugar in 100 g of solution.

hydrolysis

Splitting a molecule by adding water. Sucrose plus water gives glucose plus fructose: invert sugar.

CORE IDEAS

The story. For centuries Europe's sugar came from sugarcane grown in tropical colonies, and it was expensive. In 1747 the Berlin chemist Andreas Sigismund Marggraf reported to the Prussian Academy of Sciences that the roots of the white beet contained crystals identical to cane sugar. He extracted the juice with a solvent, let it crystallize, and compared the crystals under a microscope. His student Franz Karl Achard bred beets for higher sugar and in 1801 opened the world's first beet-sugar factory at Cunern in Silesia. When war cut France off from cane sugar, Napoleon's government encouraged beet sugar from 1811, and today about one-fifth of the world's sugar comes from beets.

How they figured it out. Marggraf's key evidence was sameness: if beet crystals had the same shape, taste and behavior as cane crystals, they were the same substance. Chemists later confirmed it at the molecular level: both are sucrose, $C_{12}H_{22}O_{11}$, and no test can tell refined beet sugar from refined cane sugar.

The kitchen science. Sugars are the smallest carbohydrates. **Monosaccharides** such as glucose and fructose share the formula $C_6H_{12}O_6$ but arrange their atoms differently. Two of them join, releasing a water molecule, to make a **disaccharide**: sucrose (table sugar), lactose (milk sugar) or maltose. Acid, heat or the enzyme invertase reverses this by **hydrolysis**, splitting sucrose into glucose and fructose, called **invert sugar**; honey is largely invert sugar made by bees. Sugars differ in sweetness: taking sucrose as 1.0, fructose is roughly 1.2–1.8, glucose about 0.7 and lactose about 0.2–0.4. Sugar does more than sweeten. It holds water, browns, and lowers the freezing point: the more sugar dissolved in a sorbet, the softer it freezes.

Sorbet makers aim for about 25–30 °Bx; much less and it freezes into a rock, much more and it never sets.

Think it through. A food scientist measures sugar concentration with a refractometer, which reads °Bx from how strongly the liquid bends light. You can calculate it instead: add up the sugar from every ingredient and divide by the total mass.

Let's cook. You will make a strawberry sorbet designed by calculation to about 24–25 °Bx, and test smaller batches made sweeter and less sweet. The skill is **designing a recipe by numbers**: deciding the target, calculating the amounts, then checking the result.

PICTURE STUDY



Still Life with Quince, Cabbage, Melon and Cucumber, Juan Sánchez Cotán, c. 1602 · Oil on canvas · San Diego Museum of Art

Image: Wikimedia Commons, public domain

Sánchez Cotán was a Spanish painter who later became a lay brother in a Carthusian monastery. His still lifes show ordinary produce hung in a cool window, the way Spanish households kept food fresh.

Look closely

- Follow the curve from the quince at the top left down to the cucumber at the right. Which items do you think are the sweetest?
- Find the cut melon. What would its Brix be, roughly: higher or lower than a strawberry?
- Why are the quince and cabbage hung on strings?
- Look at the dark background. What does it do to the colors of the fruit?

Talk about it

1. Fruits make sugar from sunlight, water and carbon dioxide. Which fruit here would make the best sorbet, and why?
2. Quinces are too hard and sour to eat raw, but cooked with sugar they become sweet and soft. What is happening to their sugars and fibers?

3. A monk painted plain vegetables with this much care. What does that suggest about how he saw ordinary food?

Safety first. Wash strawberries under running water and hull them on a board with a paring knife. If you use a blender, keep the lid on and your hands out of the jar. Taste tests use clean spoons, and families check for allergies first.

KITCHEN LAB

Designing a Sorbet by Brix

How does sugar concentration change how hard a sorbet freezes? You will make one family batch at about 24 °Bx and three small test cups at about 15, 25 and 35 °Bx, freeze them side by side and compare.

You will need

- A blender or food processor
- A digital scale and a small saucepan
- A metal loaf pan and three identical small cups with lids
- A fork for scraping and a spoon for a scoop test
- A ruler
- Your lab notebook

Strawberry Sorbet

Serves 6 (about 3 cups) · Prep 15 min · Freeze 4–6 hr

Ingredients

- 450 g (1 lb) ripe strawberries, washed and hulled
- 150 g (¾ cup) sugar
- 120 g (½ cup) water
- 30 g (2 tablespoons) lemon juice
- Pinch of salt

Method

1. Heat the sugar and water in the saucepan, stirring, until the sugar dissolves. Cool the syrup.
2. Blend the strawberries, cooled syrup, lemon juice and salt until very smooth. Strain out seeds if you like.
3. Pour into the loaf pan, cover, and freeze. Every 45 minutes for 3–4 hours, scrape and stir with a fork, breaking up ice at the edges.

4. When firm but scoopable, serve. If it freezes hard overnight, let it stand 10 minutes before scooping.
5. Wash the blender, pan and saucepan.

Allergy check: Contains none of the major allergens.

Steps

1. **Hypothesis.** Predict which test cup will be hardest and which softest after 4 hours, and why.
2. **Design.** Before blending the full batch, set aside three 100 g portions of plain blended strawberry purée (without syrup). Calculate how much sugar to dissolve into each to reach about 15, 25 and 35 °Bx, counting the fruit's own 7%.
3. **Prepare.** Stir the sugar into each test cup until fully dissolved; label and freeze them on the same shelf with the family batch.
4. **Measure.** After 4 hours, push a spoon into each cup with the same gentle force and record how far it goes (mm), and describe the texture.
5. **Sweetness panel.** Have three family members rank the cups by sweetness and by how much they like the texture.
6. **Analyze.** Graph spoon depth against °Bx. Is the relationship steady or does it change sharply somewhere?
7. **Conclusion.** Explain the result with freezing-point depression: dissolved sugar keeps some water from freezing.
8. Clean up and serve the family batch.

Tips

- Very ripe fruit can be 9–10% sugar; less ripe, 5%. If your berries are sour, aim for the higher end of the Brix range.
- A tablespoon of corn syrup or honey in place of some sugar makes sorbet smoother, because glucose and fructose crystallize less readily.
- Taste the cold base before freezing; cold dulls sweetness, so it should taste a little too sweet.

Check your work

☐ I can name and describe common monosaccharides and disaccharides.

- ☐ I can calculate Brix and solve for the sugar needed to reach a target.
- ☐ I designed and tested a sorbet by sugar concentration.

LAB NOTEBOOK

1. Draw glucose and fructose joining into sucrose, with the water molecule that leaves, then the hydrolysis that reverses it.
2. Record your Brix calculations and the spoon-depth graph.
3. Write the sorbet recipe with your chosen Brix and one change for next time.

KEY FORMULAS

$$^\circ\text{Bx} = \frac{m_{\text{sugar}}}{m_{\text{total}}} \times 100$$

$$\text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6\ (\text{glucose}) + \text{C}_6\text{H}_{12}\text{O}_6\ (\text{fructose})$$

From history. Sugarcane was first domesticated in New Guinea, and crystallized sugar was being made in India by the early centuries A.D.; the word “sugar” comes through Arabic from the Sanskrit *śarkarā*. Beet sugar made sugar cheap in Europe in the 1800s, and today sugar from both plants is one of the world’s most common foods.

WORKED EXAMPLES

Example 1. A sorbet base is 450 g strawberries (about 7% sugar), 150 g sugar, 120 g water and 30 g lemon juice (about 2% sugar). Find its Brix.

Show solution

1. Sugar from fruit: $0.07 \times 450\ \text{g} = 31.5\ \text{g}$; from lemon $0.02 \times 30 = 0.6\ \text{g}$.
2. Total sugar: $31.5 + 150 + 0.6 = 182.1\ \text{g}$.
3. Total mass: $450 + 150 + 120 + 30 = 750\ \text{g}$.
4. $^\circ\text{Bx} = \dfrac{182.1}{750} \times 100 = 24.3$.

Answer: About 24 °Bx, at the low end of the scoopable range.

Example 2. How much more sugar must be added to the 750 g base to reach 28 °Bx?

Show solution

1. Let x be the added sugar: $\dfrac{182.1 + x}{750 + x} = 0.28$.
2. $182.1 + x = 210 + 0.28x \;\Rightarrow\; 0.72x = 27.9 \;\Rightarrow\; x = 38.8$ g.

Answer: About 39 g more sugar (roughly 3 tablespoons).

Example 3. Show that the hydrolysis of sucrose conserves mass, using molar masses (sucrose 342.3 g/mol, water 18.0, glucose and fructose 180.2 each). How many grams of invert sugar come from 100 g of sucrose?

Show solution

1. Left: $342.3 + 18.0 = 360.3$ g; right: $180.2 + 180.2 = 360.4$ g. Mass is conserved.
2. From 100 g sucrose: $100 \times \dfrac{360.4}{342.3} = 105.3$ g.

Answer: About 105 g of invert sugar: the added water becomes part of the sugars.

Example 4. A sweet tea has 30 g of sucrose in 355 g of drink. Find its Brix, and the teaspoons of sugar (4 g each).

Show solution

1. $\dfrac{30}{355} \times 100 = 8.5$ °Bx.
2. $\dfrac{30\text{ g}}{4\text{ g/tsp}} = 7.5$ tsp.

Answer: About 8.5 °Bx, about 7½ teaspoons of sugar.

PRACTICE

1. Easy Which two monosaccharides make up sucrose? Lactose?

   Show answer

   Sucrose: glucose and fructose. Lactose: glucose and galactose.

2. **Easy** Find the Brix of 20 g sugar dissolved in 180 g water.

   Show answer

   $20/200 \times 100 = 10\ ^\circ\text{Bx}$

3. **Easy** In what year did Marggraf announce sugar in beets, and in what year did Achard open the first beet-sugar factory?

   Show answer

   1747 and 1801.

4. **Medium** How many grams of sugar are in 500 g of a 12 °Bx juice?

   Show answer

   $0.12 \times 500 = 60\ \text{g}$

5. **Medium** Explain why honey stays liquid longer and tastes sweeter than a sucrose syrup of the same concentration.

   Show answer

   Honey is mostly fructose and glucose (invert sugar); fructose is sweeter than sucrose, and the mixture of sugars crystallizes less readily.

6. **Medium** You mix 300 g of 10 °Bx juice with 100 g of sugar. Find the new Brix.

   Show answer

   $(30 + 100)/400 \times 100 = 32.5\ ^\circ\text{Bx}$

7. **Medium** Why does a sorbet with too little sugar freeze into a hard block?

   Show answer

   With little dissolved sugar, almost all the water freezes into large connected ice crystals; sugar lowers the freezing point and keeps some water liquid.

8. **Medium** Refined beet sugar and refined cane sugar: can any test tell them apart? Why?

   Show answer

   No practical test; both are pure sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$.

9. Hard How much water must be added to 400 g of a 30 °Bx syrup to dilute it to 20 °Bx?

Show answer

Sugar 120 g; $120/(400+w)=0.20 \Rightarrow w=200$ g.

10. Hard Taking sucrose's sweetness as 1.0 and fructose's as 1.5, about how many grams of fructose give the sweetness of 30 g of sucrose?

Show answer

$30/1.5=20$ g

11. Challenge A recipe needs 1 kg of sorbet base at 27 °Bx using mango purée at 14% sugar and sugar syrup made of equal masses of sugar and water. Find the masses of purée and syrup.

Show answer

Let m = purée, $1000-m$ = syrup (50% sugar): $0.14m+0.50(1000-m)=270$ so $0.36m=230$, $m=639$ g; syrup 361 g.

COMMON MISTAKES

- Forgetting the fruit's own sugar when calculating Brix.
- Adding undissolved sugar to cold purée; it stays gritty. Dissolve it in syrup or stir until clear.
- Judging sweetness at room temperature; cold food tastes less sweet.

Make it a game · Count the Teaspoons. Take a drink label from the pantry. Before reading, guess the teaspoons of sugar per serving. Convert grams to teaspoons at about four grams each and compare. Closest guess wins a point; do three labels. Explain what degrees Brix measures. Tell how Marggraf found sugar in beets and Achard built a factory.

Scripture. "My son, eat thou honey, because it is good; and the honeycomb, which is sweet to thy taste:" (Proverbs 24:13, KJV)

Sweetness is God's good gift. Two chapters later Proverbs adds a caution about eating too much (Proverbs 25:16); good things are enjoyed in their place.

3.2 Caramelization and the Candy Stages: Milton Hershey's Caramels

OBJECTIVES

- Tell how Milton Hershey learned candy making and built the Lancaster Caramel Company (1886) after several failures.
- Explain how boiling a sugar syrup raises its concentration and boiling point, name the candy stages, and distinguish caramelization from the Maillard reaction.
- Make a caramel sauce safely, testing the candy stages with a thermometer and the cold-water test.

> **Warm-up.** Look at a jar of caramel sauce, a hard candy, a soft caramel and a lollipop (or pictures of them). All are mostly sugar. Write down what you think makes them so different.

WATCH

Science of caramel

Kitchen Matters · 9:51

https://www.youtube.com/watch?v=zN8K5DSsZBM

> **WHEN TO WATCH**
> During session 1. Copy the sugar–water phase diagram and the table of candy stages; you will use both in the lab.

KEY TERMS

caramelization

The browning and breakdown of sugar by heat alone, above about 320 °F (160 °C), producing hundreds of new flavor and color compounds.

Maillard reaction

Browning from sugars reacting with amino acids (from proteins) at lower temperatures, as in toast or seared meat. Milk caramels brown partly this way.

candy stages

Points along a boiling sugar syrup's rising temperature, named for how a drop behaves in cold water: thread, soft ball, firm ball, hard ball, soft crack, hard crack.

crystallization

Sugar molecules lining up into solid crystals. Candy makers prevent it (for smooth caramel) or encourage it (for fudge).

boiling-point elevation

The rise in a solution's boiling point as more solute is dissolved.

CORE IDEAS

The story. Milton Hershey was born in Pennsylvania in 1857 and left school at about 14 to apprentice with a confectioner in Lancaster. His own candy shops in Philadelphia, Chicago and New York all failed. In Denver, working for a caramel maker, he learned that caramels made with fresh milk stayed soft and kept well. Back in Lancaster he founded the Lancaster Caramel Company in 1886 and it succeeded spectacularly. In 1900 he sold it for one million dollars to concentrate on milk chocolate, and he built the town of Hershey and, with his wife Catherine, a school for orphaned boys.

How they figured it out. Candy makers learned by eye and hand long before thermometers were common: a drop of hot syrup in cold water that forms a soft ball, or that snaps into brittle threads, told them how far the syrup had cooked. Hershey's insight was about ingredients: milk proteins and fat changed the flavor, color and texture of the caramel. Food scientists now know that the stages are really a measure of **concentration**, and that the browning of milk caramels is largely the Maillard reaction between milk sugars and milk proteins.

The kitchen science. As a sugar syrup boils, water leaves and the sugar concentration rises, and so does the boiling point. Each temperature corresponds to a concentration, and each concentration gives a texture when cooled: about 235–245 °F (112–118 °C) is the **soft-ball** stage (about 85% sugar, for fudge), 250–265 °F (121–129 °C) the **hard-ball** stage (about 90%, for nougat and soft caramel candy), and 300–310 °F (149–154 °C) the **hard-crack** stage (about 99%, for lollipops and brittle). Above

about 320 °F (160 °C), with almost no water left, sucrose begins to break apart and recombine into hundreds of new compounds: **caramelization**. The color deepens from gold to amber to mahogany, the sweetness drops and bitterness rises. Stirring or stray crystals can make a syrup crystallize suddenly into a grainy mass; a little acid, corn syrup or invert sugar helps prevent it.

Let's cook. You will cook a caramel sauce, taking samples at each candy stage on the way up. Molten sugar is hotter than boiling water and sticks to skin, so the skill is **handling hot sugar safely**: a heavy pan, a parent present, long sleeves, and cream added slowly and at arm's length.

PICTURE STUDY



Milton S. Hershey, Unknown photographer, c. 1905 · Photograph · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

By the time of this photograph Hershey had already made his fortune in caramels and was building a chocolate factory and a whole town among the dairy farms of Derry Township, Pennsylvania.

Look closely

- Look at his clothes and posture. What impression did he want to give?
- Imagine this man at fourteen, stirring a copper kettle of boiling sugar. What would he have had to learn?
- Look at his expression. Does he look like someone who gave up easily?

Talk about it

1. Hershey failed in three cities before he succeeded. What did each failure teach him?
2. Why would fresh milk make a better caramel? Think about proteins, fat and the Maillard reaction.
3. Hershey used much of his fortune to found a school for orphans. What does that suggest about how he saw his success?

Safety first. Cooking sugar reaches over 300 °F and sticks to skin: work with a parent present, wear long sleeves, use a heavy, deep saucepan, and never touch or taste hot syrup. Add the cream slowly and at arm's length; it bubbles up violently. Keep children and pets away from the stove, and have a bowl of ice water ready in case of a splash on the skin.

KITCHEN LAB

Stages on the Way to Caramel

As one batch of syrup cooks toward caramel, you will take tiny samples at each stage, test them in cold water and record the temperature, then finish the batch as a caramel sauce.

You will need

- A heavy-bottomed 3-quart saucepan (light-colored inside if possible)
- A candy thermometer or instant-read thermometer
- A glass of ice water and a small metal spoon for samples
- A heat-proof spatula, oven mitts and long sleeves
- A heat-proof jar for the finished sauce
- Your lab notebook

Caramel Sauce with Apple Slices

Serves About 1¼ cups sauce (8–10 servings) · Cook 15–20 min · Cool 15 min

Ingredients

- 200 g (1 cup) sugar
- 60 g (¼ cup) water
- 180 mL (¾ cup) heavy cream, warmed
- 45 g (3 tablespoons) butter, in pieces
- ½ teaspoon salt
- 1 teaspoon vanilla extract
- 4 crisp apples, sliced, for dipping

Method

1. Measure everything before you start and set it beside the stove. Warm the cream in a small pan or the microwave.
2. Stir the sugar and water in the heavy saucepan just until the sugar is evenly wet. Clip on the thermometer. Cook over medium heat without stirring; swirl the pan gently if it colors unevenly.

3. Take samples for the lab as it passes each stage (see the lab steps).
4. When the caramel reaches a deep amber, about 340–350 °F (171–177 °C), remove it from the heat.
5. Standing back, pour in the warm cream a little at a time while whisking with a long whisk; it will bubble up hard. Stir in the butter, salt and vanilla.
6. Cool at least 15 minutes before tasting. Serve with apple slices. Refrigerate leftovers up to 2 weeks and rewarm gently.
7. Fill the pan with hot water and let it soak; the hardened caramel will dissolve.

Allergy check: Contains milk (cream and butter). For a milk-free sauce, use full-fat coconut milk and coconut oil; the flavor and color will differ, since the Maillard reaction with milk proteins is part of caramel flavor.

Steps

1. **Prediction.** Predict the temperature at which the syrup will first turn pale gold.
2. **Water test.** Before you start, measure the boiling point of water in your kitchen and note the difference from 212 °F.
3. **Samples.** As the syrup heats, drip a few drops into the ice water at about 230, 240, 250, 270, 300 and 320 °F. Record what each does: threads, soft ball, firm ball, hard ball, soft crack, hard crack.
4. **Color.** From 320 °F up, record the color every 5 °F (pale gold, gold, amber, deep amber) and the smell.
5. **Finish** the sauce and serve it with apples.
6. **Analyze.** Compare your stage temperatures with the standard table, corrected for your boiling point. Calculate the sugar concentration at each stage from the table's percentages and the mass of water lost.
7. **Conclusion.** Explain why the temperature kept rising as the syrup boiled, unlike plain water, and what changed chemically above 320 °F.
8. Clean up by soaking, not scrubbing, the caramel.

Tips

- A light-colored pan lets you see the caramel color; a dark pan hides it.

- If crystals form on the sides of the pan, brush them down with a wet pastry brush.
- Caramel goes from perfect to burnt in about 30 seconds above 350 °F; take it off the heat a little early, because the pan keeps cooking it.

Check your work

- ☐ I can explain how boiling raises sugar concentration and the boiling point.
- ☐ I can name the candy stages and their temperatures.
- ☐ I made caramel safely and explained caramelization.

LAB NOTEBOOK

1. Make a table of the candy stages: temperature (°F and °C), approximate sugar %, cold-water behavior, and a candy made at that stage.
2. Draw a graph of temperature against time for the syrup, marking each stage and the start of caramelization.
3. Paste a color strip (paint it or describe it) of your caramel from pale gold to deep amber.

KEY FORMULAS

$$\text{water to evaporate} = m_{\text{start}} - \frac{m_{\text{sugar}}}{x_{\text{target}}}$$

$$q = mL_v$$

From history. Hershey's first milk chocolate bars went on sale in 1900. He built the town of Hershey, Pennsylvania, with houses, parks and a trolley for his workers, and in 1909 he and his wife founded the Hershey Industrial School for orphan boys, now the Milton Hershey School, which still serves thousands of children.

Example 1. A syrup starts with 200 g sugar and 60 g water. What is its starting concentration, and how much water must boil off to reach the soft-ball stage (85% sugar)?

Show solution

1. Start: $\dfrac{200}{260} \times 100\% = 76.9\%$.
2. Total mass at 85%: $\dfrac{200\ \text{g}}{0.85} = 235.3\ \text{g}$.
3. Water to boil off: $260 - 235.3 = 24.7\ \text{g}$.

Answer: About 77% to start; about 25 g of water must evaporate.

Example 2. How much energy goes into evaporating that 24.7 g of water? (Use the latent heat of vaporization, 2,260 J/g.)

Show solution

1. $q = (24.7\ \text{g})(2260\ \text{J/g}) = 55{,}800\ \text{J}$.

Answer: About 56 kJ, in addition to the energy that heats the syrup.

Example 3. Convert the soft-ball (240 °F), hard-crack (305 °F) and caramel (340 °F) temperatures to Celsius.

Show solution

1. $\frac{5}{9}(240 - 32) = 115.6\ ^\circ\text{C}$; $\frac{5}{9}(305 - 32) = 151.7\ ^\circ\text{C}$; $\frac{5}{9}(340 - 32) = 171.1\ ^\circ\text{C}$.

Answer: About 116 °C, 152 °C and 171 °C.

Example 4. A candy recipe made at sea level says to cook to 240 °F. You live at 5,000 ft. What temperature should you cook to?

Show solution

1. Water boils about $\frac{5000}{500} = 10$ °F lower, at 202 °F.
2. Candy stages depend on how far above the boiling point of water the syrup is, so subtract the same amount: $240 - 10 = 230$ °F.

Answer: About 230 °F. A good method: test the boiling point of water on the day, and adjust by the difference from 212 °F.

PRACTICE

1. Easy In what year did Hershey found the Lancaster Caramel Company?

   Show answer

   1886.

2. Easy At about what temperature does sucrose begin to caramelize?

   Show answer

   About 320 °F (160 °C).

3. Easy Name the candy stage used for lollipops and brittle.

   Show answer

   Hard crack, about 300–310 °F.

4. Medium How is caramelization different from the Maillard reaction?

   Show answer

   Caramelization is sugar alone breaking down at high heat; the Maillard reaction is sugars reacting with amino acids, at lower temperatures.

5. Medium Why does the temperature of a boiling sugar syrup keep rising while the temperature of boiling water does not?

   Show answer

   As water evaporates, the syrup becomes more concentrated, and more concentrated solutions have higher boiling points.

6. **Medium** A syrup of 300 g sugar and 100 g water is boiled to 90% sugar. How much water evaporates?

   Show answer

   $$400 - 300/0.90 = 400 - 333.3 = 66.7 \text{ g}$$

7. **Medium** Convert 235 °F to Celsius.

   Show answer

   $$\tfrac{5}{9}(203) = 112.8\ ^\circ\text{C}$$

8. **Medium** Why add the cream slowly and stand back?

   Show answer

   The 340 °F caramel instantly boils the water in the cream to steam, which bubbles up violently and can splash molten sugar.

9. **Hard** A fudge recipe written for sea level says 238 °F. On the day you cook, water boils at 207 °F. What temperature should you cook to?

   Show answer

   $$238 - (212 - 207) = 233\ ^\circ\text{F}$$

10. **Hard** Why do candy makers add a little corn syrup or lemon juice to a caramel?

    Show answer

    Corn syrup (glucose) and invert sugar from acid break up the regular sucrose molecules, making it harder for crystals to form, so the caramel stays smooth.

11. **Challenge** Estimate the energy needed to boil off the water in the challenge syrup of problem 6 and heat it, if 400 g of syrup (c ≈ 2.5 J/(g·°C)) is first heated from 20 °C to 104 °C, then 66.7 g of water evaporates.

    Show answer

    Heating: $(400)(2.5)(84) = 84{,}000$ J; evaporating: $(66.7)(2260) = 150{,}700$ J; total about 235 kJ. (The syrup also keeps warming as it concentrates, so the true total is higher.)

COMMON MISTAKES

- Stirring the syrup as it boils, which can start crystallization.
- Walking away during the last minutes; caramel burns fast.
- Using a thin pan, which scorches sugar in spots.

- Pouring cold cream into caramel all at once, which seizes and splatters.

> **Make it a game · Candy Stage Match.** Make fourteen cards: seven candy stages and seven temperature ranges, thread through hard crack. Shuffle them face down and play memory match with your parent. Explain each match using boiling-point elevation. Then say how a syrup's concentration changes as it boils. Tell how Hershey recovered from failures to build his caramel business.

3.3 Starch and Gelatinization: Thomas Kingsford's Cornstarch

OBJECTIVES

- Tell how Thomas Kingsford developed a process to make starch from corn in 1842.
- Describe amylose and amylopectin and explain gelatinization in a sauce, with temperatures.
- Compare flour and cornstarch as thickeners with a line-spread test, and make a cheese sauce from a roux.

> **Warm-up.** Stir 1 teaspoon of cornstarch into ¼ cup of cold water and let it sit 2 minutes. Does it dissolve? Now microwave it for 30 seconds, stir, and microwave 15 seconds more (carefully). What changed?

WATCH

What is Starch Gelatinization? | Knead to Know Basis | BAKERpedia

BAKERpedia · 4:38

https://www.youtube.com/watch?v=BMOgr-Buiag

> **WHEN TO WATCH**
> During session 1. Note the two temperatures shown for the start and end of gelatinization.

BACKUP VIDEO

Polysaccharides - Starch, Amylose, Amylopectin, Glycogen, & Cellulose - Carbohydrates

The Organic Chemistry Tutor · 6:32

https://www.youtube.com/watch?v=1HMMYCqZonU

During the worked examples. Shows the α-1,4 and α-1,6 bonds that make amylose straight and amylopectin branched, and why cellulose is different.

KEY TERMS

starch
A polymer of glucose that plants store in granules for energy.

amylose
The straight-chain form of starch, joined by α-1,4 bonds; about 20–30% of most starches.

amylopectin

The highly branched form of starch, with α-1,6 branch points; most of the rest of the starch.

gelatinization

The swelling and bursting of starch granules heated in water, which releases chains that tangle and thicken the liquid.

roux

Equal parts (by weight) of fat and flour cooked together; used to thicken sauces such as béchamel.

slurry

Starch stirred into cold liquid so the granules separate before they are heated, preventing lumps.

CORE IDEAS

The story. In the early 1800s starch was a valuable industrial product, used to stiffen laundry and make paste, and most of it came from wheat or potatoes. Thomas Kingsford, a superintendent at a starch works in Jersey City, New Jersey, experimented with corn, which was cheap and abundant in America. In 1842 he developed a reliable process to separate pure starch from corn kernels by soaking, grinding and settling them. His company moved to Oswego, New York, in 1848, and Kingsford's corn starch soon became a household thickener for puddings and sauces.

How they figured it out. Separating starch depends on its physical properties: starch granules are denser than water and do not dissolve in it cold, so ground grain stirred in water lets the starch settle to the bottom while proteins and fiber are washed away. Kingsford's challenge was to do it cleanly and on a large scale with corn, whose starch is bound more tightly to protein than potato starch is.

The kitchen science. Starch is a polymer of glucose. **Amylose** is a long straight chain; **amylopectin** is a huge, bushy, branched molecule. Plants pack both into hard granules. In cold water the granules just settle. Heated in water, starting around 140–150 °F (60–65 °C) for corn and wheat starch, they absorb water and swell many times their size; as the temperature rises toward boiling they leak amylose and burst, and the released chains tangle with water: **gelatinization**. The liquid thickens and turns from cloudy to more translucent. Cornstarch is nearly pure starch and thickens fully near a boil to a glossy, clear gel. Flour is only about 70–75% starch (the rest is protein and more), so it takes about twice as much flour as cornstarch for the same thickness, and it makes an opaque sauce. Stir starch into cold liquid (a **slurry**) or

coat it with fat (a **roux**) first; dumped into hot liquid, the outsides of clumps gelatinize instantly and seal dry flour inside as lumps.

Let's cook. You will make a stovetop macaroni and cheese with a béchamel sauce thickened by a roux. The skill is **making a smooth roux-thickened sauce**: cooking the roux for a minute or two, adding the milk gradually while whisking, and bringing it to a simmer so the starch fully gelatinizes.

PICTURE STUDY



The Gleaners, Jean-François Millet, 1857 · Oil on canvas · Musée d'Orsay, Paris

Image: Wikimedia Commons, public domain

Millet painted three women gleaning: gathering the grain left in the field after the harvest. In the Law of Moses farmers were told to leave the gleanings for the poor (Leviticus 19:9–10), as Boaz did for Ruth.

Look closely

- Find the three women. What is each one doing with her hands?
- Look far back to the haystacks and the workers. How is their harvest different from the women's?
- Look at the light. What time of day is it?
- What will the wheat they gather become, and what part of it is starch?

Talk about it

1. A wheat kernel is about 70% starch. How many steps lie between this field and a sauce on your stove?
2. Why do you think the law allowed the poor to glean? What does it teach about waste?
3. Millet's painting shows hard labor with dignity. How does knowing the work behind flour change how you treat it?

> **Safety first.** A boiling starch sauce is thick, holds heat and can spit: stir with a long whisk, keep the heat at medium, and be careful when tasting (cool a spoonful first). Carry the pasta pot with mitts and drain it away from you.

KITCHEN LAB

Flour vs. Cornstarch: The Line-Spread Test

How much does thickening power differ between flour and cornstarch, and how does concentration change it? You will make four small test sauces and measure their thickness with a simple, standard food-science test, then make the family recipe.

You will need

- A small saucepan and a whisk
- A digital scale and measuring spoons
- A thermometer
- A sheet of paper with four lines drawn from a center circle, under a glass plate or a clear sheet protector
- A 2-inch-wide ring (a cookie cutter or a cut-off can) and a timer
- A large pot and a colander
- Your lab notebook

Stovetop Macaroni and Cheese

Serves 6 · Prep 10 min · Cook 25 min

Ingredients

- 1 lb (450 g) elbow macaroni
- 56 g (4 tablespoons) butter
- 32 g (¼ cup) all-purpose flour
- 720 mL (3 cups) milk, warmed
- 225 g (8 oz) sharp cheddar, coarsely grated
- 30 g (½ cup) grated parmesan
- 1 teaspoon salt, ½ teaspoon dry mustard, ¼ teaspoon pepper, pinch of paprika

Method

1. Cook the macaroni in well-salted boiling water until just tender; drain.

2. Meanwhile, melt the butter in a large saucepan over medium heat. Whisk in the flour and cook, whisking, 1–2 minutes until bubbling and smelling slightly toasty but not brown (the roux).
3. Slowly pour in the warm milk, about ½ cup at a time, whisking until smooth after each addition.
4. Bring to a gentle simmer, whisking, and cook 3–4 minutes until thick enough to coat a spoon (about 200 °F).
5. Turn the heat to low. Stir in the cheeses a handful at a time until melted, then the seasonings.
6. Stir in the macaroni and serve. Refrigerate leftovers within 2 hours; reheat with a splash of milk to 165 °F.
7. Soak the saucepan in warm water, then wash it and the pot.

Allergy check: Contains wheat (pasta and flour) and milk (butter, milk and cheese). For wheat-free, use gluten-free pasta and thicken with 16 g (2 tablespoons) cornstarch in a cold-milk slurry instead of the roux.

Steps

1. **Hypothesis.** Predict how much thicker a 4% starch sauce will be than a 2% sauce, and whether flour or cornstarch thickens more per gram.
2. **Make four test sauces** of 200 g milk each: (A) 6 g flour, (B) 12 g flour, (C) 3 g cornstarch, (D) 6 g cornstarch. Make each starch into a slurry with 2 tablespoons of the cold milk, whisk it into the rest, and heat, whisking, to a simmer (about 200 °F) for 1 minute.
3. **Cool** each to 140 °F (60 °C) so they are tested at the same temperature.
4. **Line-spread test.** Set the ring on the center of the lined sheet, fill it level with sauce, lift it straight up and start the timer. After 60 seconds, read the spread on each of the four lines and average them.
5. **Observe** each sauce's clarity (cloudy or translucent) and gloss.
6. **Cook** the family mac and cheese.
7. **Analyze.** Calculate the starch percentage of each test sauce and graph spread against starch percentage for flour and for cornstarch.
8. **Conclusion.** Which thickener is stronger per gram? Why is flour sauce cloudier? Use what you know about flour's protein and starch content.

9. Clean up; starch sauces wash off more easily after soaking.

Tips

- Warm milk added to a roux makes fewer lumps than cold milk, but either works if you add it slowly.
- Cheese melts most smoothly into a sauce over low heat; boiling makes it grainy and oily.
- If a sauce does get lumpy, whisk hard or pour it through a sieve.

Check your work

- ☐ I can describe amylose and amylopectin and explain gelatinization.
- ☐ I compared thickeners with a line-spread test and calculated starch percentages.
- ☐ I made a smooth roux-thickened sauce.

LAB NOTEBOOK

1. Draw a starch granule in cold water, swelling at 150 °F, and burst and tangled at 200 °F.
2. Record the line-spread data in a table and graph it.
3. Write the béchamel method in your own words: the ratio of butter to flour to milk.

KEY FORMULAS

$$\text{starch \% of sauce} = \frac{m_{\text{starch}}}{m_{\text{sauce}}} \times 100\%$$

$$\text{line spread (average)} = \frac{d_1 + d_2 + d_3 + d_4}{4}$$

From history. Corn wet-milling, the industry Kingsford helped begin, now separates corn into starch, oil, protein and fiber. Much of the starch is turned by enzymes into corn syrups. Cornstarch is also used to make biodegradable plastics and as the dusting on many foods to keep them from sticking.

WORKED EXAMPLES

Example 1. A béchamel uses 32 g flour (about 72% starch) in 720 g milk with 56 g butter. Find the starch percentage of the sauce.

Show solution

1. Starch: $0.72 \times 32\ \text{g} = 23.0\ \text{g}$.
2. Sauce mass: $32 + 720 + 56 = 808\ \text{g}$.
3. $\dfrac{23.0}{808} \times 100\% = 2.85\%$.

Answer: About 2.9% starch, a medium-thick sauce.

Example 2. How much cornstarch (about 98% starch) gives the same starch content as 32 g of flour?

Show solution

1. $m = \dfrac{23.0\ \text{g}}{0.98} = 23.5\ \text{g}$, about 3 tablespoons of cornstarch versus 4 of flour.

Answer: About 23–24 g. In practice cooks use about half as much cornstarch as flour, because cornstarch also thickens more strongly per gram of starch.

Example 3. In a line-spread test, a sauce spreads 5.2, 4.8, 5.0 and 5.4 cm along four lines in 60 seconds. A second sauce spreads 7.8, 8.4, 8.0 and 7.8 cm. Find each average and the percent difference.

Show solution

1. Sauce 1: $\dfrac{20.4}{4} = 5.10\ \text{cm}$; sauce 2: $\dfrac{32.0}{4} = 8.00\ \text{cm}$.
2. $\dfrac{2.90}{6.55} \times 100\% = 44\%$.

Answer: 5.1 cm and 8.0 cm, a 44% difference. The sauce that spreads less is thicker.

Example 4. Starch gelatinization in a sauce is complete near 203 °F. Convert to Celsius, and explain why a sauce that reached only 160 °F would be thinner than the recipe expects.

Show solution

1. $\frac{5}{9}(203 - 32) = 95\ ^\circ\text{C}$.
2. At 160 °F (71 °C) granules have begun to swell but have not fully swollen and released their chains.

Answer: 95 °C. Bring a starch-thickened sauce to a simmer to reach full thickness.

PRACTICE

1. Easy What is the monomer of starch?

   Show answer

   Glucose.

2. Easy Name the straight and branched forms of starch.

   Show answer

   Amylose (straight) and amylopectin (branched).

3. Easy In what year did Kingsford develop his corn-starch process?

   Show answer

   1842.

4. Medium Why must starch be mixed with cold liquid or fat before going into a hot liquid?

   Show answer

   To separate the granules; otherwise the outsides of clumps gelatinize instantly and seal dry starch inside as lumps.

5. Medium A pudding uses 28 g cornstarch (98% starch) in a total of 750 g. Find its starch percentage.

   Show answer

   $27.4/750 = 3.7\%$

6. Medium Why is a cornstarch gel clearer than a flour-thickened sauce?

Show answer

Flour contains protein and other particles that scatter light; cornstarch is nearly pure starch.

7. Medium A sauce reaches only 165 °F and seems thin. What should the cook do and why?

Show answer

Bring it to a simmer (about 200 °F); gelatinization is not complete until near boiling.

8. Medium Waxy cornstarch is nearly 100% amylopectin. Predict how its gel would differ after a day in the refrigerator compared with ordinary cornstarch (about 25% amylose).

Show answer

It would stay softer and weep less, because amylopectin retrogrades (re-forms crystals) much more slowly than amylose.

9. Hard Four line-spread readings are 6.2, 6.6, 6.0 and 6.4 cm. A target of 5.0–5.5 cm is “just right” for a gravy. Is the gravy too thick or too thin, and what would you do?

Show answer

Average 6.3 cm: too thin. Simmer a few minutes more, or add a small cornstarch slurry and bring back to a simmer.

10. Hard Flour is 72% starch and cornstarch 98%. In a sauce, cooks use 2 tablespoons (16 g) of flour or 1 tablespoon (8 g) of cornstarch for the same thickness per cup. Compare the starch in each and explain what this suggests.

Show answer

Flour 11.5 g starch; cornstarch 7.8 g. Cornstarch thickens more per gram of starch, likely because its granules swell more freely without flour’s proteins and fats.

11. **Challenge** Why is cellulose, also a glucose polymer, indigestible to humans, while starch is digestible?

    Show answer

    Cellulose links glucose with β-1,4 bonds that our enzymes cannot break; starch uses α-1,4 and α-1,6 bonds that amylase can.

COMMON MISTAKES

- Dumping flour or cornstarch straight into a hot sauce.
- Stopping before the sauce simmers, so it never reaches full thickness.
- Boiling a cornstarch sauce hard for a long time or stirring it violently, which breaks the swollen granules and thins it again.
- Adding cheese over high heat, which makes it grainy.

Make it a game · Granule Sketch. Set a ninety-second timer and sketch a starch granule from cold to gelatinized in a hot sauce, labeling amylose and amylopectin and the temperatures where thickening begins. Your parent checks it against the lesson and points out any error. Redraw it with a flour roux next to a cornstarch slurry. Mention Kingsford's 1842 process.

Scripture. “He causeth the grass to grow for the cattle, and herb for the service of man: that he may bring forth food out of the earth;” (Psalm 104:14, KJV)

Starch is sunlight stored by a plant as food. Every grain of wheat and kernel of corn is the Creator bringing forth food out of the earth.

3.4 Retrogradation: Boussingault and the Stale Loaf

OBJECTIVES

- Tell how Jean-Baptiste Boussingault showed in 1852 that bread stales even when it does not dry out.
- Explain starch retrogradation, why it is fastest at refrigerator temperatures, and how reheating reverses it.
- Measure staling under three storage conditions and use day-old bread in a panzanella.

> **Warm-up.** Three days ago, seal one slice of soft sandwich bread in a bag on the counter, one in the refrigerator and one in the freezer (thaw it sealed for an hour). Today, squeeze each. Which feels stalest? Did any of them dry out?

WATCH

Starch Retrogradation | The Science of Stale Bread

PostHarvest · 3:40

https://www.youtube.com/watch?v=13ICPBTnqKo

> **WHEN TO WATCH**
> During session 1, after the story. Watch the animation of amylose and amylopectin lining up as bread cools.

BACKUP VIDEO

How a Chemist Makes the Softest Bread You'll Ever Eat

Reactions · 15:59

https://www.youtube.com/watch?v=3ziMBDPMuP8

After the lab. A chemist uses the tangzhong method (a cooked flour paste) to make bread that resists staling; notice how she uses gelatinization to slow retrogradation.

KEY TERMS

retrogradation

The slow re-forming of ordered, partly crystalline regions in cooked starch as it cools and ages, squeezing out water and firming the food.

staling

The loss of softness and fresh flavor in bread, caused mainly by retrogradation, not by drying.

glass transition

The change of a starch–water system from rubbery to brittle; below it, molecules can barely move, so retrogradation nearly stops (as in a freezer).

syneresis

Liquid seeping out of a gel as it ages, as when a starch pudding "weeps."

panzanella

A Tuscan salad of day-old bread, tomatoes and vegetables, made to use bread that would otherwise be wasted.

CORE IDEAS

The story. Jean-Baptiste Boussingault was a French chemist known for careful measurement in agricultural science. In 1852 he tested the common belief that bread goes stale because it dries out. He sealed fresh bread so that it could not lose moisture and weighed it over several days.

How they figured it out. The sealed bread became hard and crumbly, yet its mass hardly changed: it had not dried. When Boussingault heated the stale bread in its sealed container to about 140 °F (60 °C) and above, it became soft again, nearly like fresh bread. Since no water had been added, something inside the bread had changed and then changed back with heat. A century later, X-ray studies showed that starch in stale bread had re-formed crystalline regions, and that heating melts them.

The kitchen science. Baking gelatinizes the starch in bread: granules swell, amylose leaks out, and chains tangle with water. As the loaf cools, **amylose** lines up quickly, within hours, setting the crumb so it can be sliced. Over the next days the branches of **amylopectin** slowly line up too, forming firm, ordered bundles and pulling water from the gluten: **retrogradation**. The crumb becomes firm and crumbly and the

crust leathery. Retrogradation is fastest at refrigerator temperatures (about 32–50 °F), so bread stales several times faster in the refrigerator than on the counter. In a freezer, the starch is below its glass transition and the chains can hardly move, so freezing nearly stops staling. Reheating above about 140 °F melts amylopectin crystals and softens the bread for a while. Fats, sugars, emulsifiers and cooked flour pastes such as tangzhong all slow retrogradation.

Let's cook. For cooks, stale bread is an ingredient. Firm, drier bread cubes hold their shape in a salad, a bread pudding or stuffing where fresh bread would turn to mush. You will make panzanella, a Tuscan bread salad, with day-old bread toasted into croutons. The skill is **timing a salad** so the bread soaks up dressing without going soggy.

PICTURE STUDY



Paul Hermann Baking Loaves of Lithuanian Rye, Farm Security Administration / Office of War Information photographer, c. 1942 · Photograph · Library of Congress, Washington, D.C.
Image: Wikimedia Commons, public domain

This photograph comes from the U.S. government's wartime project to record American life. A baker takes rye loaves of the kind Lithuanian American families bought fresh every few days out of a big bakery oven; the photograph was made around 1942.

Look closely

- Find the loaves. Are they large or small? Why would a family buy a big loaf?
- Find the racks of loaves beside the oven. What is beginning to happen to their starch as they cool?
- Look at the cloth in the baker's hand. Why does he need it?
- Rye bread is dense and moist. Do you think it would stale faster or slower than soft white bread?

Talk about it

1. Before refrigerators and plastic bags, how did families keep bread from going stale, and what did they do with it when it did?
2. Why would a neighborhood bakery bake fresh every day instead of once a week?

3. Rye bread contains gums called pentosans that hold water. How might they affect staling?

Safety first. Toast bread cubes in a 375 °F oven with mitts and watch them, as they go from golden to burnt quickly. Cut tomatoes and cucumber with a sharp knife on a board with a damp towel underneath, using the claw grip.

KITCHEN LAB

Three Ways to Stale a Loaf

Does storage temperature change how fast bread stales, and can heat reverse it? You will track slices stored on the counter, in the refrigerator and in the freezer, measure firmness and mass, test reheating, and then put stale bread to good use.

You will need

- A loaf of plain soft white sandwich bread (the same loaf for every sample)
- Zip-top bags, a marker and a digital scale
- A ruler, a sharp knife and a full can (about 15 oz) to press with
- A sheet pan and oven mitts
- A large bowl
- Your lab notebook

Panzanella (Tuscan Bread Salad)

Serves 6 · Prep 25 min · Bake 12 min · Rest 20 min

Ingredients

- 300 g (about 6 cups) day-old crusty bread, cut into 1-inch cubes
- 3 tablespoons olive oil and ½ teaspoon salt for toasting
- 700 g (1½ lb) ripe tomatoes, cut into bite-size pieces
- 1 cucumber, halved and sliced
- ½ small red onion, thinly sliced
- 1 cup fresh basil leaves, torn
- Dressing: ⅓ cup (75 mL) olive oil, 3 tablespoons apple cider vinegar or lemon juice, 1 small clove garlic minced, 1 teaspoon Dijon mustard, ½ teaspoon salt, ¼ teaspoon pepper

Method

1. Heat the oven to 375 °F (190 °C). Toss the bread cubes with 3 tablespoons oil and ½ teaspoon salt on a sheet pan and bake 10–12 minutes, stirring once, until golden and crisp outside.

2. Put the tomatoes in a large bowl with a pinch of salt and let them sit 10 minutes to release their juices. Add the cucumber and onion.
3. Shake the dressing ingredients in a jar until blended.
4. Add the toasted bread and dressing to the vegetables, toss, and let stand 15–20 minutes so the bread soaks up the juices but keeps some chew.
5. Toss in the basil just before serving. Panzanella is best the same day.
6. Wash the board, knife, pan and bowl.

Allergy check: Contains wheat (bread). Dijon mustard is not one of the nine major U.S. allergens, but some people are allergic to mustard. For wheat-free, use day-old gluten-free bread.

Steps

1. **Day 0.** From one fresh loaf, weigh three slices, label them Counter, Fridge and Freezer, and seal each in its own bag. Cut a 2-cm cube from a fourth slice and measure its compression under the can for 10 seconds; this is your fresh baseline.
2. **Store** the bags in their places for three days.
3. **Day 3.** Thaw the freezer slice in its bag for an hour. Weigh each slice and calculate moisture loss. Cut a 2-cm cube from each and measure compression the same way.
4. **Reheat.** Warm the refrigerator slice, still in foil, in a 300 °F oven for 5 minutes, cool 5 minutes, and test it again.
5. **Analyze.** Calculate compression percentages and firming rates. Rank the conditions.
6. **Cook** the panzanella with day-old bread.
7. **Conclusion.** Explain your results with retrogradation and the glass transition, and compare them with Boussingault's experiment.
8. Clean up; use leftover stale bread for croutons or breadcrumbs.

Tips

- Keep bread you will eat within two days on the counter; freeze the rest, sliced, and toast it straight from frozen.
- Crusty bread for panzanella should be firm but not rock hard. If it is very hard, sprinkle it with water before toasting.

- Salting the tomatoes first draws out juice by osmosis (Unit 8) that becomes part of the dressing.

Check your work

- ☐ I can explain retrogradation and why bread stales fastest in the refrigerator.
- ☐ I measured staling under three conditions with mass and compression.
- ☐ I used stale bread well in a recipe.

LAB NOTEBOOK

1. Draw starch chains in fresh bread (loose and tangled) and in stale bread (lined up in bundles), and the change back when reheated.
2. Make a data table and bar graph of compression percentage for fresh, counter, fridge, freezer and reheated slices.
3. List five dishes from different cultures made to use stale bread.

KEY FORMULAS

$$\text{compression } \% = \frac{h_0 - h_1}{h_0} \times 100\%$$

$$\text{moisture loss } \% = \frac{m_0 - m_1}{m_0} \times 100\%$$

From history. Commercial bakers fight staling with enzymes, emulsifiers and careful packaging; most American sandwich bread contains an anti-staling enzyme that trims amylopectin branches so they cannot line up as easily. Cultures everywhere invented dishes for stale bread: panzanella and ribollita in Italy, French toast (*pain perdu*, "lost bread") in France, bread pudding in England, and *fattoush* in the Levant.

WORKED EXAMPLES

Example 1. A sealed slice weighs 30.4 g fresh and 30.1 g after three days. Find the percent moisture loss. Could drying explain staling?

Show solution

1. $\dfrac{30.4 - 30.1}{30.4} \times 100\% = 0.99\%.$

Answer: About 1%. Bread is about 35–40% water, so it lost only a tiny part of its water; drying cannot explain the hardness, just as Boussingault found.

Example 2. A 2.0-cm cube of bread compresses to 1.2 cm under a can of soup when fresh, and to 1.7 cm after three days in the refrigerator. Find the compression percentage each time.

Show solution

1. Fresh: $\dfrac{2.0 - 1.2}{2.0} \times 100\% = 40\%$.
2. Refrigerated: $\dfrac{2.0 - 1.7}{2.0} \times 100\% = 15\%$.

Answer: 40% and 15%: the refrigerated bread is much firmer.

Example 3. If the counter slice's compression fell from 40% to 30% in three days and the refrigerated slice's from 40% to 15%, compare the average rates of firming.

Show solution

1. Counter: $\dfrac{10 \text{ points}}{3 \text{ days}} = 3.3 \text{ points/day}$.
2. Refrigerator: $\dfrac{25}{3} = 8.3 \text{ points/day}$.
3. $\dfrac{8.3}{3.3} = 2.5$.

Answer: The refrigerated bread firmed about 2½ times as fast.

PRACTICE

1. Easy What did Boussingault's sealed bread show?

   Show answer

   Bread stales even when it does not lose moisture, so staling is not just drying.

2. Easy Where does bread stale fastest: counter, refrigerator or freezer?

   Show answer

   Refrigerator.

3. Easy A slice loses 0.5 g from 32.0 g. Find the percent moisture loss.

   Show answer

   $0.5/32.0 = 1.6\%$

4. Medium Why does warming a stale roll make it soft again for a while?

Show answer

Heat melts the crystalline regions of retrograded starch, loosening the chains; as it cools, they slowly re-form.

5. Medium Why does freezing nearly stop staling?

Show answer

In the freezer the starch–water system is below its glass transition, so the starch chains can hardly move to line up.

6. Medium A cube compresses 45% fresh and 27% after 2 days. Find the change per day.

Show answer

$18/2 = 9$ percentage points per day.

7. Medium Which forms of starch retrograde within hours, and which over days?

Show answer

Amylose within hours (setting the loaf); amylopectin over days (staling).

8. Medium Why does day-old bread make better panzanella or stuffing than fresh bread?

Show answer

Its firmer, retrograded crumb absorbs liquid without collapsing into mush.

9. Hard Suggest two ingredient changes that would make a sandwich bread stay soft longer, and explain each.

Show answer

Add fat or an emulsifier (it coats starch and slows the chains from lining up); use a cooked flour paste (tangzhong) or more sugar (holds water and interferes with crystallization).

10. Hard Rice pudding left overnight in the refrigerator becomes stiff and weeps a little liquid. Explain both.

Show answer

Starch retrogrades in the cold, firming the gel; as chains bundle tightly they squeeze out water (syneresis).

11. **Challenge** Design an experiment to test whether adding 10% butter (by flour weight) slows staling in homemade bread. Name the variables, controls and measurements.

    Show answer

    Independent: butter or no butter. Dependent: compression % over 0, 1, 2 and 3 days. Controlled: same flour, water, yeast, salt, rise times, bake, slice thickness, storage. Replicate with several cubes per day.

COMMON MISTAKES

- Storing bread in the refrigerator to keep it fresh.
- Assuming stale bread is dry and adding water to it before reheating whole loaves.
- Dressing a bread salad too early, so the bread turns to mush.
- Throwing away stale bread instead of using it.

> **Make it a game · Stale Forecast.** Your parent names three storage spots for a slice of bread: counter, refrigerator and freezer. Write your ranking of staleness after three days and the reason, using retrogradation and glass transition. Then explain how syneresis shows up in a pudding. Discuss how Boussingault's 1852 experiment showed it is not just drying.

3.5 Fiber and Digestion: Beaumont's Window into the Stomach

OBJECTIVES

- Tell how William Beaumont studied digestion through his patient Alexis St. Martin's stomach opening (1822–1833), and how Denis Burkitt drew attention to dietary fiber in the 1970s.
- Explain how starch and sugars are digested by enzymes, and what soluble and insoluble fiber do.
- Test salivary amylase and compare the gel-forming power of fiber sources, and bake a fiber-rich baked oatmeal.

> **Warm-up.** Chew a plain, unsalted cracker without swallowing for 60 seconds (skip this if you have a wheat allergy; use a bite of plain white rice instead). Does the taste change? Write down what you notice before the lesson explains it.

WATCH

Soluble vs Insoluble Fiber - Alissa Lupu - NewYork-Presbyterian

NewYork-Presbyterian Hospital · 2:37

https://www.youtube.com/watch?v=-z7CAsDxmMs

> **WHEN TO WATCH**
> During session 1, after the story. List the foods the dietitian names for each kind of fiber.

KEY TERMS

digestion
The breaking of food into molecules small enough to absorb, mostly by enzymes.

amylase
An enzyme in saliva and from the pancreas that breaks starch into maltose and other small sugars.

dietary fiber
Carbohydrates from plants that human enzymes cannot digest, such as cellulose, pectin and beta-glucan.

soluble fiber
Fiber that dissolves or swells in water to form a gel, such as oat beta-glucan and fruit pectin.

insoluble fiber

Fiber that does not dissolve, such as the cellulose in wheat bran and vegetable skins, which adds bulk.

Daily Value (DV)

The reference amount used on food labels; for fiber, 28 g per day.

CORE IDEAS

The story. On June 6, 1822, at a fur-trading post on Mackinac Island, Michigan, a young voyageur named Alexis St. Martin was accidentally shot in the side at close range. The army surgeon William Beaumont treated him and saved his life, but the wound healed leaving a permanent opening (a fistula) from the outside into his stomach. Beaumont realized he had an opportunity no physician had ever had: to watch digestion as it happened in a living person.

How they figured it out. Between 1825 and 1833 Beaumont performed more than two hundred experiments. He lowered pieces of food on silk threads into the stomach and pulled them out at intervals to see how far they had been digested. He drew out gastric juice and showed it digested meat in a vial kept warm at body temperature, proving digestion was chemical, not just grinding. In 1833 he published *Experiments and Observations on the Gastric Juice and the Physiology of Digestion*. The story has a hard side: St. Martin did not always want to be studied, and modern medical ethics, which require free and informed consent, grew partly from reflecting on cases like his. A century and a half later, the Irish surgeon Denis Burkitt, working in Africa, noticed that some diseases of the bowel common in Britain were rare among rural Africans who ate much more fiber, and in the 1970s he drew worldwide attention to dietary fiber.

The kitchen science. Digestion of carbohydrates starts in the mouth: **salivary amylase** begins cutting starch into maltose, which is why a cracker held in your mouth starts to taste sweet. The stomach's acid mostly stops amylase, and pancreatic amylase finishes the job in the small intestine, where enzymes on the intestinal wall split maltose, sucrose and lactose into glucose, fructose and galactose for absorption. **Fiber** is the plant carbohydrate our enzymes cannot break, because of the way its sugar units are joined. **Soluble fiber**, such as the beta-glucan in oats and pectin in apples, absorbs water to form a thick gel, slowing digestion and helping us feel satisfied. **Insoluble fiber**, such as wheat bran and vegetable skins, adds bulk and keeps the digestive tract moving. Helpful bacteria in the large intestine ferment

some fiber. The Daily Value for fiber is 28 g, and most Americans eat about half that; whole grains, beans, fruits and vegetables are the best sources.

Let's cook. You will bake a pan of baked oatmeal with apples, a breakfast rich in soluble fiber. The skill is **calculating nutrition from ingredients**: adding up the fiber in each ingredient to find the fiber per serving.

PICTURE STUDY



Still Life with Cabbage and Clogs, Vincent van Gogh, 1881 · Oil on paper on panel · Van Gogh Museum, Amsterdam

Image: Wikimedia Commons, public domain

This is one of Van Gogh's very first paintings, made while he was teaching himself to paint in the Netherlands. He chose the plain food and shoes of poor farm families, the people whose meals he admired for their honesty.

Look closely

- Find the cabbage. Which parts would be tough and fibrous, and which tender?
- Find the potatoes. What kind of carbohydrate are they mostly made of?
- Look at the clogs. What do they tell you about who ate this food?
- Notice the dark, earthy colors. What mood do they create?

Talk about it

1. A farm family eating cabbage, potatoes and dark bread would have eaten far more fiber than most people today. Why might that be?
2. Cooking softens cabbage. What happens to its fiber and to the cell walls when it cooks?
3. Van Gogh painted ordinary food with respect. What plain, fiber-rich food in your kitchen deserves a second look?

> **Safety first.** Check allergies before any taste test; skip the cracker test with a wheat allergy. Core and slice apples with a paring knife on a stable board. The baking dish comes out of a 375 °F oven: use mitts and set it on a rack.

KITCHEN LAB

Enzymes and Gels: A Digestion Lab

Two short investigations: your own salivary amylase at work, and a comparison of how much gel different fiber sources form in water. Then you will bake a high-fiber breakfast and calculate its fiber.

You will need

- Plain unsalted crackers (or plain cooked white rice)
- Four clear glasses, a digital scale and a timer
- Rolled oats, ground flaxseed, wheat bran (or whole-wheat flour) and white flour
- A thin spoon and a ruler for the tilt test
- A 9 × 13-inch baking dish
- Your lab notebook

Baked Oatmeal with Apples and Cinnamon

Serves 8 · Prep 15 min · Bake 35–40 min

Ingredients

- 270 g (3 cups) old-fashioned rolled oats
- 30 g (¼ cup) ground flaxseed
- 2 teaspoons ground cinnamon, 1½ teaspoons baking powder, ½ teaspoon salt
- 600 mL (2½ cups) milk
- 2 large eggs
- 80 g (¼ cup) maple syrup or honey
- 40 g (3 tablespoons) melted butter or oil
- 1 teaspoon vanilla extract
- 2 apples, cored and diced
- Optional: 60 g (½ cup) chopped walnuts or raisins

Method

1. Heat the oven to 375 °F (190 °C) and grease the baking dish.
2. Stir the oats, flax, cinnamon, baking powder and salt in a large bowl.
3. Whisk the milk, eggs, syrup, melted butter and vanilla in another bowl.
4. Spread the apples (and nuts or raisins) in the dish, pour the oat mixture over them, then pour on the milk mixture. Press the oats down so they are moistened.
5. Bake 35–40 minutes, until set in the center and golden on top (the center reaches at least 160 °F because it contains eggs).
6. Cool 10 minutes and cut into 8 squares. Refrigerate leftovers up to 4 days; reheat to 165 °F.
7. Wash the bowls and whisk; soak the dish.

Allergy check: Contains milk and eggs; tree nuts if you add walnuts. Oats are naturally wheat-free but often cross-contaminated; use oats labeled gluten-free if needed. For milk-free, use soy or oat milk (soy is an allergen). Honey is never given to babies under one year.

Steps

1. **Amylase test.** Chew a plain cracker for 60 seconds without swallowing, rating its sweetness from 0 to 5 at 0, 20, 40 and 60 seconds. Repeat with a second family member. Explain any increase.
2. **Gel test, set-up.** In four glasses put 10 g of rolled oats, 10 g ground flax, 10 g wheat bran and 10 g white flour, each with 100 g of water at about 140 °F. Stir each 30 seconds and let stand 15 minutes.
3. **Gel test, measure.** Tilt each glass to 45° and time how long the surface takes to flow 2 cm, or rate thickness from 1 (watery) to 5 (gel). Which fiber forms the most gel?
4. **Hypothesis check.** Before the gel test you should have predicted the order. Compare your prediction with the result.
5. **Bake** the baked oatmeal. Use the package labels of your ingredients to calculate fiber per serving and %DV.
6. **Conclusion.** Explain the cracker result with amylase and the gel results with soluble and insoluble fiber.
7. Clean up: rinse the gel glasses before the gels dry.

Tips

- Use the Nutrition Facts on your own packages for fiber values; they differ by brand.
- Ground flax forms gel much faster than whole seeds, because grinding breaks the seed coat.
- Baked oatmeal freezes well in squares for quick breakfasts.

Check your work

- ☐ I can explain how starch is digested and what amylase does.
- ☐ I can distinguish soluble and insoluble fiber and name food sources of each.
- ☐ I calculated fiber per serving and %DV from ingredient labels.

LAB NOTEBOOK

1. Draw the path of a bite of oatmeal from mouth to large intestine, labeling where starch, sugars and fiber are each broken down or not.
2. Record the amylase ratings and the gel-test results in tables.
3. Write the baked oatmeal recipe with your fiber calculation.

KEY FORMULAS

$$\text{fiber per serving} = \frac{\sum \text{fiber in ingredients}}{\text{number of servings}}$$

$$\%\,\text{DV} = \frac{\text{amount per serving}}{28\ \text{g}} \times 100\%$$

From history. Beaumont's book listed the digestion times of many foods and was translated into several languages. Alexis St. Martin outlived Beaumont by nearly thirty years and died in Quebec in 1880 at the age of about 78.

WORKED EXAMPLES

Example 1. A baked oatmeal uses 270 g rolled oats (10 g fiber per 100 g), 2 apples (4.4 g fiber each) and 30 g ground flaxseed (27 g fiber per 100 g). Find the fiber per serving if it serves 8, and the percent Daily Value.

Show solution

1. Oats: $2.70 \times 10 = 27.0$ g; apples: $2 \times 4.4 = 8.8$ g; flax: $0.30 \times 27 = 8.1$ g.
2. Total: $27.0 + 8.8 + 8.1 = 43.9$ g.
3. Per serving: $\dfrac{43.9}{8} = 5.5$ g. %DV: $\dfrac{5.5}{28} \times 100\% = 20\%$.

Answer: About 5.5 g of fiber per serving, 20% of the Daily Value.

Example 2. Amylase splits starch into maltose. How many grams of maltose ($C_{12}H_{22}O_{11}$, 342 g/mol) can come from 10.0 g of starch? Each glucose unit in starch has a mass of 162 g/mol, and two units plus one water make one maltose.

Show solution

1. Moles of glucose units: $\dfrac{10.0\ \text{g}}{162\ \text{g/mol}} = 0.0617$ mol.
2. Moles of maltose: $\dfrac{0.0617}{2} = 0.0309$ mol.
3. Mass: $0.0309 \times 342 = 10.6$ g.

Answer: About 10.6 g; the extra mass is the water added in hydrolysis.

Example 3. The Dietary Guidelines suggest about 14 g of fiber for every 1,000 Calories of food energy. A teenager's day provides 2,600 Calories. How much fiber is that, and what percent of it does one serving of baked oatmeal supply?

Show solution

1. $14 \times \dfrac{2600}{1000} = 36.4$ g.
2. $\dfrac{5.5}{36.4} \times 100\% = 15\%$.

Answer: About 36 g a day; one serving supplies about 15% of it. (Calories here are simply a measure of food energy.)

PRACTICE

1. Easy Where does starch digestion begin, and what enzyme starts it?

Show answer

In the mouth, with salivary amylase.

2. Easy What is the Daily Value for fiber on a food label?

Show answer

28 g.

3. Easy A cereal has 7 g fiber per serving. Find the %DV.

Show answer

$7/28 = 25\%$

4. Medium Name one source each of soluble and insoluble fiber.

Show answer

Soluble: oats, beans, apples (pectin). Insoluble: wheat bran, whole-wheat flour, vegetable skins.

5. Medium What did Beaumont's experiment with gastric juice in a warm vial show?

Show answer

That digestion is a chemical process carried out by the juice itself, not only grinding by the stomach.

6. Medium Why can't human enzymes digest cellulose?

Show answer

Its glucose units are joined by β-1,4 bonds that human enzymes cannot break.

7. Medium A recipe has 36 g of fiber in total and serves 6. Find fiber per serving and %DV.

Show answer

6 g; 21%.

8. Medium Why does soluble fiber help people feel satisfied after a meal?

Show answer

It forms a thick gel that slows the emptying of the stomach and the absorption of sugars.

9. Hard Why did the cracker taste sweeter after 60 seconds, but a piece of table sugar would not change?

Show answer

Amylase broke starch into maltose, a sugar we taste as sweet; table sugar is already sugar and amylase does not act on it.

10. Hard Using 14 g of fiber per 1,000 Calories, how much fiber is suggested for a day of 2,200 Calories? What fraction is supplied by 2 servings of baked oatmeal at 5.5 g each?

Show answer

30.8 g; $11/30.8 = 36\%$.

11. Challenge Beaumont found that boiled rice was digested in about an hour, but some meats took several hours. Suggest reasons from what you know about starch, protein and fat.

Show answer

Cooked (gelatinized) starch is rapidly broken by amylase and does not need stomach acid; proteins need pepsin and acid to unfold and cut, and fat slows stomach emptying, so meals of meat take longer.

COMMON MISTAKES

- Assuming “brown” bread is whole grain; check that the first ingredient is a whole grain.
- Adding a lot of fiber suddenly; increase it gradually and drink water with it.
- Thinking fiber is a nutrient you digest for energy like starch; most of it passes through, doing its work along the way.

Make it a game · Digestion Relay. Write ten digestive events on cards: chewing, amylase in saliva, stomach churning, absorption, fiber moving along, and others. Shuffle and race to put them in order, then compare against the lesson. Do it twice for a record. Separate soluble from insoluble fiber with an example of each. Tell what William Beaumont saw.

UNIT 3

Carbohydrates

Carbohydrates are the sugars, starches and fibers that give us most of our food energy and much of the texture of our food. In this unit you will meet them from the smallest to the largest: the simple sugars and their sweetness, the sugars transformed by heat into caramel, the starch chains that swell and thicken a sauce, the same chains slowly lining up again in a stale loaf, and the fibers that our enzymes cannot digest at all.

The stories follow Marggraf's beet crystals, Milton Hershey's caramel kettles, Thomas Kingsford's corn starch, Boussingault's sealed loaf and William Beaumont's window into a living stomach. The labs measure Brix, candy stages, line spread, bread firmness and gel strength, and the recipes are a sorbet designed by calculation, caramel sauce, stovetop mac and cheese, panzanella from day-old bread and a fiber-rich baked oatmeal.

PREREQUISITES

- Unit 2: water's polarity and hydrogen bonds; q = mcΔT and latent heat
- Solving linear equations and working with percentages
- Comfort at the stove with a parent at home; a parent present for the hot-sugar lab

MASTERY CHECKLIST

- ☐ I can name and describe monosaccharides, disaccharides and polysaccharides and explain hydrolysis.
- ☐ I can calculate Brix and design a recipe to a target sugar concentration.
- ☐ I can explain the candy stages, boiling-point elevation and caramelization, and handle hot sugar safely.
- ☐ I can describe amylose and amylopectin and explain gelatinization and retrogradation.
- ☐ I can explain how carbohydrates are digested and what soluble and insoluble fiber do.
- ☐ I can calculate nutrient amounts per serving and %DV from ingredient labels.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FDA: How to Understand and Use the Nutrition Facts Label**: Free. Explains Daily Values, including the 28 g Daily Value for fiber used in Lesson 3.5.
- **A candy thermometer that clips to the pan**: Optional. An instant-read thermometer works for Lesson 3.2 if it reads above 350 °F, but a clip-on thermometer frees your hands.
- **A refractometer (Brix meter)**: Optional and inexpensive. Lets you measure the Brix of juices and sorbet bases directly instead of calculating them.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

3.1 **Sugars, Sweetness and Brix: Marggraf's Beet**

3 sessions of 50–90 minutes (plus freezing time)

3.2 Caramelization and the Candy Stages: Milton Hershey's Caramels

3 sessions of 50–90 minutes

3.3 Starch and Gelatinization: Thomas Kingsford's Cornstarch

3 sessions of 50–90 minutes

3.4 Retrogradation: Boussingault and the Stale Loaf

3 sessions of 50–90 minutes

3.5 Fiber and Digestion: Beaumont's Window into the Stomach

3 sessions of 50–90 minutes

Unit 3 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **5 pts**
   Name the monosaccharides that make up sucrose, lactose and maltose.

2. **6 pts**
   A sorbet base contains 600 g fruit purée at 9% sugar and 160 g sugar, with 140 g water. Find its Brix.

3. **7 pts**
   How much sugar must be added to 800 g of a 15 °Bx juice to reach 25 °Bx?

4. **6 pts**
   Explain why sugar makes sorbet softer.

5. **5 pts**
   What did Marggraf discover in 1747, and why did it matter?

6. **7 pts**

   A syrup of 400 g sugar and 150 g water is boiled to the hard-crack stage (99% sugar). How much water must evaporate, and how much energy does that take (L = 2,260 J/g)?

7. **6 pts**

   Distinguish caramelization from the Maillard reaction, and say which mostly browns a milk caramel.

8. **5 pts**

   A fudge recipe says 238 °F at sea level; water boils at 203 °F in your kitchen. What temperature should you cook to?

9. **6 pts**

   Describe gelatinization, with temperatures.

10. **6 pts**

    A gravy uses 24 g flour (72% starch) in 600 g of total liquid. Find its starch percentage, and the cornstarch (98% starch) needed for the same starch content.

11. **6 pts**

    Why does a roux or slurry prevent lumps?

12. **7 pts**

    Describe Boussingault's 1852 experiment and its conclusion.

13. **6 pts**

    A bread cube compresses 42% fresh, 33% after 3 days on the counter and 18% after 3 days in the refrigerator. Find each average firming rate and their ratio.

14. **6 pts**

    What did Beaumont learn from Alexis St. Martin, and what ethical lesson do doctors draw from the case today?

15. **6 pts**

    A recipe has 52 g of fiber and serves 8. Find fiber per serving and %DV (DV = 28 g).

16. **10 pts**

Short essay (5–7 sentences): Follow a slice of bread from the oven to three days later to its digestion in the body. Use the words gelatinization, retrogradation, amylase and fiber.

ANSWER KEY

1. Sucrose: glucose + fructose. Lactose: glucose + galactose. Maltose: glucose + glucose.
2. Sugar $54 + 160 = 214$ g; total 900 g; $214/900 \times 100 = 23.8$ °Bx.
3. $(120 + x)/(800 + x) = 0.25 \Rightarrow 0.75x = 80 \Rightarrow x = 107$ g
4. Dissolved sugar lowers the freezing point, so some water stays liquid at freezer temperature and ice crystals stay smaller and separated.
5. That beets contain sucrose identical to cane sugar; it led to beet-sugar factories (Achard, 1801) and cheaper sugar in Europe.
6. Final mass $400/0.99 = 404$ g; evaporate 146 g; energy $146 \times 2260 = 330{,}000$ J.
7. Caramelization: sugar alone, about 320 °F and up. Maillard: sugars with amino acids, at lower temperatures. Milk caramels brown largely by the Maillard reaction.
8. $238 - 9 = 229$ °F
9. Heated in water, starch granules absorb water and swell from about 140–150 °F, leak amylose and burst near boiling, and the chains tangle with water to thicken the liquid.
10. $17.3/624 = 2.8\%$; $17.3/0.98 = 17.6$ g.
11. It separates the starch granules (coated with fat or suspended in cold liquid) so they swell individually instead of forming gelatinized clumps around dry centers.
12. He sealed bread so it could not dry, found it staled while keeping almost the same mass, and that heating made it soft again; staling is a reversible change in the bread (starch retrogradation), not drying.
13. Counter 3 points/day; fridge 8 points/day; ratio about 2.7.
14. That digestion is a chemical process carried out by gastric juice, and how long foods take to digest. Research on people requires their free, informed consent.
15. 6.5 g; 23%.
16. Answers vary. Full credit for: starch gelatinized during baking; amylose and then amylopectin retrograde as bread cools and ages, faster in the refrigerator, reversed by reheating; amylase in saliva and from the pancreas breaks starch into maltose and then glucose; whole-grain bread's fiber is not digested by our enzymes but adds bulk and helps satiety.

UNIT PROJECT: THE FAMILY CARBOHYDRATE NOTEBOOK

Choose one family favorite that depends on carbohydrate chemistry: a pudding, a gravy, a jam, a candy, a bread or a breakfast. Explain the carbohydrate science in it in a one-page illustrated report (which sugars or starches are present, what heat and water do to them, and what happens when it is stored).

Then run a controlled experiment on one variable of the recipe (sugar amount, thickener type or amount, storage temperature or cooking temperature), with at least two trials of each treatment and a measurement such as Brix, line spread, compression or a ranked taste panel. Write it up as a full lab report and serve the best version to your family.

LOOK FOR	WHAT IT MEANS
Science explanation	Correctly explains the sugars, starch or fiber in the dish and the changes caused by heat, water and storage.
Experimental design	One variable changed, others controlled, at least two trials each.
Measurement and calculation	A real measurement with units; correct Brix, percentage or rate calculations.
Safety	Hot sugar, starch sauces and ovens handled safely with a parent present where needed.
Honest conclusion	Conclusion follows from the data, including surprises and sources of error.

UNIT 4

Proteins

Proteins are the most changeable molecules in the kitchen. Heat, acid, salt, air and even a whisk can unfold them, and once unfolded they bond to each other to set an egg, hold a foam, brown a crust, stretch a dough or turn a tough cut tender. In this unit you will learn how proteins are built from amino acids, how their shapes fold and unfold, and how cooks control those changes.

The stories follow Emil Fischer's first synthetic peptides, the investigators who found Salmonella inside clean eggs, Louis-Camille Maillard's browning tubes, Jacopo Beccari's washed dough and Peter Cooper's powdered gelatin. The labs measure foam overrun, egg-setting temperatures, browning and pH, wet gluten and braising tenderness, and the recipes are Swiss meringues, baked custard, seared pork chops, homemade pizza and beef stew.

PREREQUISITES

- Unit 1: calibrated thermometer and the USDA safe temperatures
- Unit 3: reducing sugars and caramelization
- Comfort searing and browning in a hot pan with a parent at home

MASTERY CHECKLIST

- ☐ I can describe amino acids, peptide bonds and the four levels of protein structure.
- ☐ I can explain denaturation and coagulation, egg-setting temperatures and why egg dishes are cooked to 160 °F.
- ☐ I can explain the Maillard reaction and how temperature, moisture and pH control it.
- ☐ I can explain how gluten forms and use baker's percentages.
- ☐ I can explain collagen, gelatin and why tough cuts are braised.
- ☐ I can calculate overrun, cooking yield, baker's percentages and cost per serving.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **King Arthur Baking: Baker's Percentage**: Free. A clear explanation of baker's percentages with examples, for Lesson 4.4.
- **A heavy cast-iron skillet**: Optional. Holds heat for searing (Lesson 4.3) and is useful all year. Any heavy skillet works.
- **A Dutch oven or heavy lidded pot**: Used for the braise in Lesson 4.5 and the bread in Unit 6. A heavy stockpot with a lid works for the stew.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

4.1 Amino Acids, Protein Structure and Foam: Emil Fischer's Peptides
3 sessions of 50–90 minutes (plus 2 hours of baking)

4.2 Denaturation, Custard and the 160 °F Egg Line — 3 sessions of 50–90 minutes

4.3 The Maillard Reaction: Louis-Camille Maillard's Brown Crust
3 sessions of 50–90 minutes

4.4 Gluten: Beccari's Sticky Discovery — 3 sessions of 50–90 minutes (plus rising time)

4.5 Collagen, Gelatin and the Slow Braise
3 sessions of 50–90 minutes (plus 2½–3 hours of braising)

Unit 4 Test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **5 pts**
   What did Emil Fischer propose about the structure of proteins around 1902?

2. **6 pts**

   Draw or describe what happens when two amino acids join, and name the bond and the by-product.

3. **6 pts**

   80 mL of egg whites whip to 600 mL. Find the overrun, and explain why a trace of yolk would lower it.

4. **6 pts**

   Explain why sugar and cream of tartar each make a more stable foam.

5. **7 pts**

   Give the approximate setting temperatures of egg white (start), yolk, and a stirred custard, and explain why a custard sets higher.

6. **5 pts**

   Why must egg dishes reach 160 °F, even with clean uncracked eggs?

7. **6 pts**

   Scale a custard of 4 eggs, 600 mL milk and 90 g sugar to serve 15 instead of 6.

8. **6 pts**

   Name three conditions that speed the Maillard reaction and give a kitchen example of each.

9. **6 pts**

   How many times more basic (fewer H^+ ions) is a solution at pH 8.5 than one at pH 5.5?

10. **6 pts**

    Pork chops read 139 °F off the heat and rise 7 °F while resting 3 minutes. Are they safe? Convert the final temperature to °C.

11. **6 pts**

    Name the two proteins that form gluten and what each contributes.

12. **7 pts**

    Write the baker’s percentages for 800 g flour, 560 g water, 16 g salt and 6 g yeast, and find the flour for 2,000 g of the same dough.

13. **5 pts**

    Describe Beccari’s 1728 experiment.

14. **6 pts**

    Explain why chuck is braised while tenderloin is seared.

15. **7 pts**

    1,400 g of raw chuck costing $6.80 per pound becomes 940 g cooked. Find the yield, and the cost per 100 g of cooked meat (1 lb = 454 g).

16. **10 pts**

    Short essay (5–7 sentences): A cook makes a beef stew. Explain the protein science of each stage: drying and browning the meat, simmering for an hour, simmering for three hours, and chilling the leftover liquid.

ANSWER KEY

1. That proteins are long chains of amino acids joined by peptide bonds; he built short chains in the laboratory to test it.
2. The carboxyl group of one and the amino group of the other join with loss of a water molecule, forming a peptide bond.
3. $(600 - 80)/80 = 650\%$. Yolk fat gets between unfolded proteins at the bubble walls and prevents them bonding.
4. Sugar dissolves into the bubble walls and thickens them, slowing drainage; acid (cream of tartar) helps proteins bond in a stable way and makes the foam harder to over-whip.
5. White starts about 140–145 °F, yolk about 158 °F, custard about 170–180 °F. Milk dilutes the proteins and sugar gets between them, so more heat is needed before they bond.
6. Salmonella Enteritidis can be inside the egg; 160 °F destroys it.
7. Factor 2.5: 10 eggs, 1,500 mL milk, 225 g sugar.
8. High temperature (searing at 300+ °F); dry surface (patting meat dry); higher pH (baking-soda bath for pretzels).
9. $10^3 = 1000$ times.
10. Yes, 146 °F; $\frac{5}{9}(114) = 63.3\ ^\circ\text{C}$.
11. Glutenin (elasticity, spring back) and gliadin (extensibility, stretch).
12. 100%, 70%, 2%, 0.75%; total 172.75%; $2000/1.7275 = 1158$ g flour.
13. He washed a flour-and-water dough under water until the starch rinsed away, leaving a sticky, stretchy protein mass (gluten) that behaved like animal substances.
14. Chuck is rich in collagen, which needs long moist heat to become gelatin; tenderloin has little collagen and is best cooked quickly to a lower temperature so its fibers stay juicy.
15. Yield 67%; cost $(1400/454)(6.80) = \$20.97$, per 100 g cooked $\$2.23$.
16. Answers vary. Full credit for: a dry surface and high heat give the Maillard reaction; after an hour, fiber proteins have denatured and squeezed out juice but collagen is still largely intact, so meat is tough; after three hours, collagen has unwound into gelatin and the meat is tender; chilled, the gelatin re-forms a network and the liquid sets.

UNIT PROJECT: THE EGG INVESTIGATION

Eggs show almost every protein behavior in this unit: foaming, setting, emulsifying, browning. Design and carry out a two-part investigation. Part 1: a controlled experiment on one variable of an egg dish (for example, the effect of milk-to-egg ratio on custard firmness, sugar timing on meringue stability, or acid on poached-egg shape), with at least two trials each and a measurement.

Part 2: write a one-page illustrated explanation, for a younger cook, of what happens to egg proteins in five different egg dishes your family eats, including the safe temperature for each. Serve the best result of your experiment at a family breakfast or dessert.

LOOK FOR	WHAT IT MEANS
Safety	All egg dishes eaten were cooked to 160 °F or used pasteurized eggs; raw eggs handled with clean-up and sanitizing.
Experimental design	One variable, controlled conditions, replicated trials, a real measurement.
Science explanation	Correct use of denaturation, coagulation, foams and the Maillard reaction in your own words.
Data and calculations	Clear table, correct calculations (overrun, ratios, temperatures) with units.
Communication	The one-page explanation is accurate, clear and helpful to a younger cook.

UNIT 4 · PROTEINS · LESSON 4.1 OF 50 · 3 SESSIONS OF 50–90 MINUTES (PLUS 2 HOURS OF BAKING)

4.1 Amino Acids, Protein Structure and Foam: Emil Fischer's Peptides

OBJECTIVES

- Tell how Emil Fischer showed around 1901–1902 that proteins are chains of amino acids joined by peptide bonds.
- Describe the four levels of protein structure and explain how egg-white proteins unfold to build a foam.
- Measure foam overrun and stability under three conditions, and bake Swiss-meringue cookies with the whites heated to 160 °F.

> **Warm-up.** Whisk one egg white in a clean bowl by hand for two minutes. Watch it change from a clear liquid to white foam. Where did the white color come from? What is holding the bubbles up? (Do not taste raw egg white; you will cook it in this lab.)

WATCH

Protein Structure and Folding

Amoeba Sisters · 7:46

https://www.youtube.com/watch?v=hok2hyED9go

> **WHEN TO WATCH**
> During session 1. Draw each of the four levels of structure as the video shows them.

BACKUP VIDEO

Science: The Magic of Meringue—Why Timing Matters When Whipping Egg Whites and Sugar

America's Test Kitchen · 2:40

https://www.youtube.com/watch?v=0fnWf5BvXac

Before the lab. Note when the test kitchen adds sugar and why it matters.

KEY TERMS

amino acid

A small molecule with an amino group ($–NH_2$), a carboxyl group (–COOH) and a side chain (R group). About twenty kinds build the proteins in food.

peptide bond

The bond joining two amino acids, formed when water is removed between the carboxyl group of one and the amino group of the next.

protein structure

Primary: the sequence of amino acids. Secondary: local coils (α-helix) and sheets (β-sheet). Tertiary: the whole chain folded into a 3-D shape. Quaternary: several chains together.

denaturation

The unfolding of a protein's shape without breaking its peptide bonds, by heat, acid, salt, air or whipping.

foam

Gas bubbles trapped in a liquid or solid, held by a film such as unfolded protein.

overrun

The percentage increase in volume when air is whipped into a liquid.

CORE IDEAS

The story. By 1900 chemists knew that proteins were huge molecules made largely of amino acids, but not how the amino acids were joined. Emil Fischer, a chemistry professor in Berlin already famous for working out the structures of sugars, set out to build protein-like chains himself. In 1901 he and Ernest Fourneau linked two glycine molecules into glycylglycine, and in 1902 Fischer (and, independently, Franz Hofmeister) proposed that all proteins are long chains linked by the same **peptide bond**. Fischer received the 1902 Nobel Prize in Chemistry for his work on sugars and purines, and by 1907 he had built a chain of eighteen amino acids.

How they figured it out. Fischer's method was to take proteins apart with acid, identify the amino acids that came out, then put them back together in the laboratory and compare the products with natural fragments. If the synthetic chains behaved like pieces of natural protein, digested by the same enzymes, then nature must be joining amino acids the same way. Half a century later, Linus Pauling and his colleagues proposed in 1951 how these chains coil into an α-helix, held by hydrogen bonds.

The kitchen science. Each protein's amino-acid sequence folds into a particular shape, with water-loving side chains outside and water-avoiding ones tucked inside. Egg white is about 90% water and 10% protein (ovalbumin is more than half of it). When you whip egg white, the whisk drags air into the liquid and the proteins at the surface of each bubble partly **denature**: they unfold, turn their water-avoiding parts toward the air, and bond to their neighbors, forming an elastic film around every bubble. That is a **foam.** A trace of fat (a bit of yolk, a greasy bowl) gets in between the proteins and ruins the foam. An acid such as cream of tartar, or a copper bowl, makes the foam more stable and harder to over-whip. Sugar dissolves into the film, making it thicker and slower to drain, but it slows foaming, so it is added after the whites are already foamy. Heat sets the foam by coagulating the proteins, and drying it makes a crisp meringue.

Let's cook. You will make Swiss-meringue cookies, in which the egg whites and sugar are first heated over simmering water to 160 °F (71 °C), the USDA safe temperature for egg dishes, and then whipped and baked low until dry. The skill is **whipping to stiff peaks** without over-whipping.

PICTURE STUDY



Emil Fischer's Private Laboratory, Würzburg, Unknown photographer, c. 1889 · Photograph · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Emil Fischer worked in laboratories like this one in Würzburg and later in Berlin. Here he and his students separated, purified and rebuilt the molecules of sugars and proteins by hand.

Look closely

- Find the glassware. Which pieces would you use to heat a liquid? To collect a gas?
- Look at the benches and the light. Why would a chemist want large windows?
- Find the shelves of bottles. What kinds of substances would a protein chemist need?
- Compare this laboratory with your kitchen. What tools do they share?

Talk about it

1. Fischer took proteins apart with acid and put amino acids back together. What does your kitchen do to proteins every day?
2. Why do chemists repeat a synthesis many times before they trust it?
3. How is whipping an egg white like a small chemistry experiment?

> **Safety first.** Do not taste raw egg white. Heat the egg whites and sugar to 160 °F (71 °C) before whipping and eating, as the recipe directs; whites from the test bowls are cooked too or discarded. Wash bowls, whisks and hands in hot soapy water after handling raw egg. Keep fingers and spatulas out of a running mixer.

KITCHEN LAB

What Makes a Foam Last?

How do cream of tartar and a trace of fat change an egg-white foam? You will whip three identical whites under different conditions, measure overrun and drainage, and then bake safe Swiss meringues.

You will need

- A hand or stand mixer (or a whisk and a strong arm)
- Three identical clean glass or metal bowls (not plastic, which can hold fat)
- A 1-cup measure and a 4-cup measure, a ruler
- A heat-proof bowl that fits over a saucepan, and a thermometer
- Two baking sheets lined with parchment
- Your lab notebook

Swiss Meringue Cookies

Serves About 36 small cookies · Prep 20 min · Bake 1½–2 hr · Cool in oven 1 hr

Ingredients

- 4 large egg whites (about 130 g), at room temperature, with no trace of yolk
- 200 g (1 cup) sugar
- ¼ teaspoon cream of tartar
- Pinch of salt
- 1 teaspoon vanilla extract
- Optional: 2 tablespoons cocoa powder sifted in at the end, or mini chocolate chips

Method

1. Heat the oven to 200 °F (93 °C) and line two baking sheets with parchment.
2. In a heat-proof bowl set over a pan of barely simmering water, whisk the egg whites, sugar, cream of tartar and salt constantly until the sugar

dissolves and the mixture reaches 160 °F (71 °C), about 4–6 minutes.

3. Remove from the heat and whip at high speed until thick, glossy and cool, with stiff peaks that stand straight up, about 6–8 minutes. Beat in the vanilla (and fold in cocoa or chips).
4. Spoon or pipe 1½-inch mounds onto the parchment.
5. Bake 1½–2 hours, until dry and crisp and they lift easily from the paper. Turn off the oven and leave them inside, door closed, for 1 hour more.
6. Store airtight. Wash every bowl and beater in hot soapy water.

Allergy check: Contains eggs. Chocolate chips may contain milk and soy. There is no simple egg-free swap; aquafaba (chickpea cooking liquid) makes a similar foam for an egg-free version.

Steps

1. **Hypothesis.** Predict which of the three foams will have the greatest overrun and which will drain least.
2. **Set up.** Put 1 egg white (measure its volume, about 30 mL) in each bowl: (A) plain, (B) with ⅛ teaspoon cream of tartar, (C) with ¼ teaspoon of yolk stirred in.
3. **Whip** each for exactly 3 minutes at the same mixer speed. Gently spoon the foam into the measuring cup and record its volume.
4. **Drainage.** Return each foam to a funnel or a small sieve set over a glass, and after 30 minutes measure the liquid that has drained out.
5. **Analyze.** Calculate overrun and percent drained for each. Discard the test foams, or bake them on a separate sheet with the cookies and do not eat any that were not heated to 160 °F first.
6. **Bake** the Swiss meringue cookies.
7. **Conclusion.** Explain your results with protein unfolding at the bubble surface, and how fat and acid affect it.
8. Clean up: wash all bowls and beaters in hot soapy water and sanitize the counter.

Tips

- Separate eggs cold (the yolk holds together better) but whip them at room temperature (they foam faster).

- Separate each egg over a small cup first, so one broken yolk does not ruin the whole batch.
- Humid days make meringues sticky; store them airtight as soon as they cool.

Check your work

- ☐ I can describe amino acids, peptide bonds and the four levels of protein structure.
- ☐ I can explain how a protein foam forms and what helps or harms it.
- ☐ I measured overrun and drainage and made meringues with the whites heated to 160 °F.

LAB NOTEBOOK

1. Draw two amino acids joining into a dipeptide, circling the peptide bond and the water that leaves.
2. Draw a single bubble in egg-white foam with unfolded proteins in its wall, water-avoiding parts toward the air.
3. Record the foam data in a table and a bar graph.

KEY FORMULAS

$$\text{overrun} = \frac{V_{\text{foam}} - V_{\text{liquid}}}{V_{\text{liquid}}} \times 100\%$$

$$\text{amino acid}_1 + \text{amino acid}_2 \rightarrow \text{dipeptide} + \text{H}_2\text{O}$$

From history. Fischer's student and others went on to show that enzymes are proteins, and in 1955 Frederick Sanger determined the full amino-acid sequence of insulin, the first protein sequenced, for which he received the Nobel Prize in 1958.

WORKED EXAMPLES

Example 1. Two egg whites (60 mL) whip to 480 mL of foam. Find the overrun.

Show solution

1. $\dfrac{480 - 60}{60} \times 100\% = \dfrac{420}{60} \times 100\% = 700\%.$

Answer: 700%: the foam is eight times the volume of the liquid.

Example 2. Glycine has the formula $C_2H_5NO_2$ (75.07 g/mol). Fischer joined two into glycylglycine. Find the formula and molar mass of glycylglycine.

Show solution

1. Two glycines: $C_4H_{10}N_2O_4$, $2(75.07) = 150.14$ g/mol.
2. Remove one H_2O (18.02 g/mol): $C_4H_8N_2O_3$, $150.14 - 18.02 = 132.12$ g/mol.

Answer: $C_4H_8N_2O_3$, 132.12 g/mol.

Example 3. A large egg white has a mass of 33 g and is about 10.5% protein. How much protein is in the 4 whites of the meringue recipe, and how much energy does that protein supply at 4 kcal per gram?

Show solution

1. $4 \times 33 \text{ g} \times 0.105 = 13.9 \text{ g}$.
2. $13.9 \text{ g} \times 4 \frac{\text{kcal}}{\text{g}} = 55 \text{ kcal}$.

Answer: About 14 g of protein, 55 kcal of food energy.

Example 4. A foam drains: after 30 minutes, 12 mL of liquid has collected under 480 mL of foam made from 60 mL of whites. What percentage of the original liquid drained?

Show solution

1. $\dfrac{12 \text{ mL}}{60 \text{ mL}} \times 100\% = 20\%$.

Answer: 20% drained. A more stable foam drains less.

PRACTICE

1. Easy What bond joins amino acids in a protein?

   Show answer

   The peptide bond.

2. Easy What molecule is released each time a peptide bond forms?

   Show answer

   Water.

3. **Easy** 50 mL of whites whips to 350 mL. Find the overrun.

Show answer

$300/50 = 600\%$

4. **Medium** Name the four levels of protein structure.

Show answer

Primary (sequence), secondary (helices and sheets), tertiary (3-D fold), quaternary (several chains).

5. **Medium** Why does a drop of yolk ruin an egg-white foam?

Show answer

Yolk fat gets between the unfolded proteins at the bubble walls and keeps them from bonding to each other.

6. **Medium** What does denaturation change, and what does it not change?

Show answer

It changes the protein's folded shape; it does not break the peptide bonds or change the sequence.

7. **Medium** Why is sugar added after the whites are foamy rather than at the start?

Show answer

Sugar slows the unfolding and foaming of the proteins; added later it dissolves into the bubble walls and stabilizes them.

8. **Medium** In what year did Fischer receive the Nobel Prize, and what did he propose about proteins?

Show answer

1902; that proteins are chains of amino acids joined by peptide bonds.

9. **Hard** A protein chain has 386 amino acids (like ovalbumin). How many peptide bonds and how many water molecules were released in making it?

Show answer

385 of each.

10. Hard Foam A drained 6 mL from 30 mL of white in 30 minutes; foam B drained 1 mL. Compare the percentages and suggest what B contained.

Show answer

20% and 3.3%. B probably contained cream of tartar (acid), which stabilizes the foam.

11. Challenge Explain why heating the whites to 160 °F before whipping (Swiss meringue) still allows a good foam, while boiling them would not.

Show answer

At 160 °F with plenty of sugar, the whites are pasteurized and only partly unfolded, so they still foam well. Boiling would fully coagulate the proteins into a solid that cannot stretch around bubbles.

COMMON MISTAKES

- Using a plastic bowl or one with traces of grease.
- Adding sugar too early, so the whites never foam fully.
- Over-whipping until the foam looks dry and grainy and begins to separate.
- Tasting raw egg white or meringue that was not heated.

> **Make it a game · Build a Protein.** Link twenty paper clips into a chain to model amino acids joined by peptide bonds. Then show primary, secondary, tertiary and quaternary structure by coiling, folding and joining two chains. Your parent names a level and you demonstrate it. Explain what denaturation does to your model and why a foam holds air.

4.2 Denaturation, Custard and the 160 °F Egg Line

OBJECTIVES

- Explain how heat denatures and coagulates egg proteins, and at what temperatures white and yolk set.
- Explain why egg dishes must reach 160 °F, and how sugar and milk raise the setting temperature of a custard.
- Observe eggs held at three controlled temperatures, and bake a vanilla custard checked with a thermometer.

> **Warm-up.** Think of five ways to cook an egg. For each, guess the highest temperature the egg reaches. Which ones keep the yolk runny? Which make the white rubbery?

WATCH

Time and temperature in cooking

Harvard Online · 5:05

https://www.youtube.com/watch?v=mC12B2XseqM

> **WHEN TO WATCH**
> During session 1. Copy the temperatures at which the different egg-white proteins and the yolk set.

BACKUP VIDEO

A Tasting of Culinary Science—Denaturation and Coagulation

The Culinary Institute of America · 3:29

https://www.youtube.com/watch?v=KV5i0VkHtR8

During the reading. A clear animation of a protein unfolding (denaturation) and then bonding to its neighbors (coagulation).

KEY TERMS

coagulation

Unfolded proteins bonding to each other into a network that traps water and turns a liquid into a gel or solid.

ovotransferrin and ovalbumin

Two egg-white proteins. Ovotransferrin sets first, around 140–145 °F (60–63 °C); ovalbumin, most of the white, around 175–180 °F (80 °C).

custard

Milk or cream thickened by egg proteins as they coagulate, either stirred (a sauce) or baked (set).

curdling

Overheated egg proteins bonding too tightly, squeezing out liquid into lumps.

water bath (bain-marie)

A pan of hot water around a baking dish that keeps the custard from overheating at the edges.

Salmonella Enteritidis

A type of bacteria that can be present inside an egg with an intact shell; cooking egg dishes to 160 °F destroys it.

CORE IDEAS

The story. For generations cooks assumed that a clean, uncracked egg was clean inside. In the 1980s public-health investigators in the northeastern United States traced a rising number of food-poisoning outbreaks to Grade A eggs with intact, clean shells. They found that one type of bacteria, *Salmonella* Enteritidis, could infect a hen's ovaries and get inside the egg before the shell formed.

How they figured it out. Investigators compared what sick people had eaten with what healthy people had eaten, and kept finding dishes made with raw or lightly cooked eggs: homemade mayonnaise, soft custards, Caesar dressing, lightly cooked scrambled eggs. Laboratory tests of eggs from the farms that supplied them found the bacteria inside the eggs. The response was a chain of safety rules, from vaccinating hens and refrigerating eggs at 45 °F or below to the cooking advice the USDA still gives: cook egg dishes to 160 °F (71 °C), and use pasteurized eggs for any recipe that leaves them raw. The Bible noticed long ago that a raw egg white has little taste; science now gives us another reason to cook it.

The kitchen science. Heat makes egg proteins vibrate until their weak bonds break and they **denature** (unfold); then their exposed parts bond to neighboring proteins and they **coagulate** into a network that traps water. Different proteins do this at different temperatures, which is why an egg cooked gently can have a tender white and a runny yolk. The white begins to set around 140–145 °F (60–63 °C) and becomes firm near 180 °F (80 °C); the yolk thickens around 149 °F (65 °C) and sets near 158 °F (70 °C). In a custard the egg proteins are diluted by milk and surrounded by sugar, which get between them, so a custard sets at a higher temperature, around 170–180 °F (77–82 °C), and gently. Heat it much past that and the proteins bond too tightly,

squeezing out water: the custard **curdles** or weeps. A water bath keeps the edges from overheating while the center catches up.

Let's cook. You will bake vanilla custards in a water bath and use a thermometer to take them out when the center reaches about 170–175 °F. The skill is **tempering**: whisking hot milk slowly into the eggs so they warm gradually without scrambling.

PICTURE STUDY



A Copper Cauldron, a Pestle and Mortar, a Stoneware Jug, Eggs and a Spring Onion, Jean-Siméon Chardin, c. 1734 · Oil on canvas · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Chardin painted the humble tools and ingredients of an eighteenth-century French kitchen many times. Eggs appear again and again: they were the cook's everyday thickener, binder and leavener.

Look closely

- Find the eggs. How has Chardin made their shells look smooth and round?
- Find the copper cauldron. Copper conducts heat very well. Why would a cook want that for an egg sauce?
- Find the mortar and pestle. What might a cook grind in it?
- Look at the light. Where does it fall most brightly?

Talk about it

1. In Chardin's day eggs were kept in a cool cellar, not a refrigerator. What would a cook do to make egg dishes safer?
2. How could a cook make a custard in that copper pot without a thermometer? What signs would tell her it was done?
3. Why do you think Chardin found such ordinary objects worth painting?

> **Safety first.** Cook egg dishes to 160 °F (71 °C) and never taste raw egg or custard base. Keep eggs refrigerated and discard cracked or dirty ones. The water bath is boiling hot: set the pan on the oven rack first, then pour in the hot water, and lift the custards out with tongs or a jar lifter.

KITCHEN LAB

Eggs at Three Temperatures, Then Custard

At what temperatures do the white and yolk of an egg set? You will hold eggs in water at three controlled temperatures and compare them, then bake a custard and take its temperature as it sets.

You will need

- Three saucepans (or one, used three times), an instant-read thermometer and a timer
- A slotted spoon and three small bowls
- Six 6-ounce ramekins or custard cups and a baking pan large enough to hold them
- A kettle of boiling water
- A whisk and a fine sieve
- Your lab notebook

Baked Vanilla Custard

Serves 6 · Prep 15 min · Bake 35–45 min · Chill 2 hr

Ingredients

- 480 mL (2 cups) whole milk
- 3 large eggs
- 67 g (⅓ cup) sugar
- Pinch of salt
- 1½ teaspoons vanilla extract
- Ground nutmeg or cinnamon for the tops

Method

1. Heat the oven to 325 °F (165 °C). Set the ramekins in the baking pan. Put a kettle of water on to boil.
2. Heat the milk in a saucepan until steaming and small bubbles form at the edge, about 180 °F (82 °C). Do not boil.

3. Whisk the eggs, sugar and salt in a bowl. Tempering: while whisking, pour in the hot milk a little at a time. Stir in the vanilla.
4. Pour through a sieve into a measuring cup, then into the ramekins. Sprinkle with nutmeg.
5. Set the pan on the oven rack and pour hot water into it to come halfway up the ramekins.
6. Bake 35–45 minutes, until the edges are set and the center jiggles slightly and reads 170–175 °F (77–79 °C).
7. Lift the ramekins out of the water with tongs, cool 30 minutes, then refrigerate at least 2 hours. Keep refrigerated and eat within 3 days.
8. Let the water cool before emptying the pan; wash the whisk, bowl and saucepan.

Allergy check: Contains eggs and milk. For milk-free, use a full-fat oat or soy milk (soy is an allergen); the custard will be a little softer.

Steps

1. **Prediction.** For eggs held 15 minutes at 145 °F, 158 °F and 175 °F (63, 70 and 79 °C), predict the state of the white and the yolk.
2. **Hold.** Heat water to each temperature in turn and keep it within 2 °F by adjusting the burner and adding a splash of cold water when needed. Hold one egg in the shell at each temperature for 15 minutes, recording the water temperature every 3 minutes.
3. **Observe.** Crack each egg into a bowl and describe the white (clear, milky, soft-set, firm) and yolk (runny, thick, fudgy, firm). These eggs are for observation only; the 145 °F and 158 °F eggs are not cooked enough to eat; discard them.
4. **Compare** your observations with the setting temperatures from the video.
5. **Bake** the custards, recording the center temperature of one every 5 minutes from 25 minutes on.
6. **Graph** the custard's center temperature against time.
7. **Conclusion.** Explain why the egg white set before the yolk, and why the custard needed a higher temperature to set than a plain egg yolk.
8. Clean up and sanitize the counter where raw eggs were cracked.

Tips

- If your custards weep or have bubbles and holes, they were overbaked; take them out a few degrees earlier next time.
- A folded kitchen towel under the ramekins in the water bath keeps the bottoms from overheating.
- Fresh eggs are hard to peel; they are best for custards and poaching.

Check your work

- ☐ I can explain denaturation and coagulation and the setting temperatures of egg white and yolk.
- ☐ I can explain why egg dishes are cooked to 160 °F and how sugar and milk change custard.
- ☐ I held eggs at controlled temperatures and baked a custard to a measured temperature.

LAB NOTEBOOK

1. Draw a protein folded, unfolded, and bonded to its neighbors in a network that traps water.
2. Make a thermometer diagram from 140 °F to 190 °F marking where each egg protein sets, the 160 °F safety line and the curdling zone.
3. Record your three-temperature eggs (with sketches) and the custard's heating curve.

KEY FORMULAS

$$\text{egg ratio} = \frac{m_{\text{egg}}}{m_{\text{liquid}}}$$

$$C = \tfrac{5}{9}(F - 32)$$

From history. The U.S. Food and Drug Administration's Egg Safety Rule, which took effect for large farms in 2010, requires measures to prevent Salmonella Enteritidis in laying hens and requires eggs to be refrigerated at 45 °F or below during storage and transport. Egg-related Salmonella illnesses fell substantially after these measures.

WORKED EXAMPLES

Example 1. A custard uses 3 large eggs (50 g each without shells) and 480 mL of milk (density 1.03 g/mL). Find the egg-to-milk ratio by mass.

Show solution

1. Eggs: $3 \times 50 = 150$ g; milk: $480 \times 1.03 = 494$ g.
2. Ratio: $\dfrac{150}{494} = 0.30$.

Answer: About 0.30, or 3 parts egg to 10 parts milk; a custard that sets softly. More egg makes it firmer.

Example 2. Convert the setting temperatures of ovotransferrin (143 °F), yolk (158 °F) and ovalbumin (180 °F) to Celsius.

Show solution

1. $\frac{5}{9}(143 - 32) = 61.7\ ^\circ\text{C}$; $\frac{5}{9}(158 - 32) = 70\ ^\circ\text{C}$; $\frac{5}{9}(180 - 32) = 82\ ^\circ\text{C}$.

Answer: About 62 °C, 70 °C and 82 °C.

Example 3. You want to scale a custard from 6 servings (3 eggs, 480 mL milk, 67 g sugar) to 10 servings. Find the yield factor and the new amounts. How many eggs should you use?

Show solution

1. Yield factor: $\dfrac{10}{6} = 1.67$.
2. Eggs $3 \times 1.67 = 5.0$; milk $480 \times 1.67 = 800$ mL; sugar $67 \times 1.67 = 112$ g.

Answer: 5 eggs, 800 mL (3⅓ cups) milk, 112 g sugar.

Example 4. A custard's center rises from 150 °F to 170 °F in 8 minutes near the end of baking. At that rate, how long would it take to overshoot to 185 °F, where curdling becomes likely?

Show solution

1. Rate: $\dfrac{20\ ^\circ\text{F}}{8\ \text{min}} = 2.5\ ^\circ\text{F/min}$.
2. Time: $\dfrac{15\ ^\circ\text{F}}{2.5\ ^\circ\text{F/min}} = 6\ \text{min}$.

Answer: About 6 minutes, so check the center every few minutes near the end, and remember the custard keeps cooking a little in the hot water.

PRACTICE

1. Easy What is the USDA safe minimum temperature for egg dishes?

   Show answer

   160 °F (71 °C).

2. Easy Which sets at a lower temperature, the egg white's ovotransferrin or the yolk?

   Show answer

   Ovotransferrin (about 140–145 °F); the yolk sets near 158 °F.

3. Easy Convert 175 °F to Celsius.

   Show answer

   79.4 °C

4. Medium Explain the difference between denaturation and coagulation.

   Show answer

   Denaturation is a protein unfolding; coagulation is the unfolded proteins bonding together into a network.

5. Medium Why does a custard set at a higher temperature than a plain beaten egg?

   Show answer

   Milk dilutes the proteins and sugar gets between them, so they must move faster (be hotter) before enough of them meet and bond.

6. Medium What does a water bath do for a baked custard?

Show answer

It keeps the dish near 212 °F or below at the edges, so the edges do not overcook while the center sets.

7. Medium Why did the 1980s outbreaks surprise public-health officials?

Show answer

The eggs had clean, uncracked shells; the bacteria were inside the egg, from the hen.

8. Medium Scale the custard (3 eggs, 480 mL milk) to 4 eggs. How much milk?

Show answer

$480 \times 4/3 = 640$ mL

9. Hard A custard is pulled at 165 °F and refrigerated. Two days later it has a pool of liquid. Was it underbaked or overbaked? Explain.

Show answer

Probably neither by much; weeping (syneresis) is more likely from overbaking. If pulled at 165 °F it may have been slightly underset, giving a soft custard. Liquid usually means the proteins bonded too tightly; check the thermometer and the water-bath depth.

10. Hard Why does a little lemon juice or vinegar in poaching water help the white hold together?

Show answer

Acid speeds the unfolding and bonding of egg-white proteins, so the white sets faster at the surface.

11. Challenge A recipe calls for raw eggs in a dressing. Give two safe alternatives and explain why they work.

Show answer

Use pasteurized-in-the-shell eggs (heated gently enough to kill Salmonella without cooking them) or cook the yolks with the liquid to 160 °F while stirring before finishing the dressing; or use a mustard emulsion without egg.

COMMON MISTAKES

- Pouring hot milk into eggs all at once, which scrambles them.

- Baking custard until it is firm in the center; it overcooks as it sits and in the hot water.
- Tasting raw custard base.
- Skipping the water bath, which leaves rubbery edges and a weeping custard.

> **Make it a game · Custard Rescue.** Your parent plays a baker with problems: curdled custard, rubbery egg white, runny pudding, a pale top. Diagnose each using coagulation temperatures, sugar, milk and the bain-marie. Name the 160 degrees Fahrenheit safety line and why Salmonella Enteritidis makes it matter. Five problems, ten seconds each, and tally your fixes.

> **Scripture.** “Can that which is unsavoury be eaten without salt? or is there any taste in the white of an egg?” (Job 6:6, KJV)
>
> Job knew that a plain egg white has little flavor. Cooks have always seasoned and cooked eggs; today we also cook them for safety.

4.3 The Maillard Reaction: Louis-Camille Maillard's Brown Crust

OBJECTIVES

- Tell how Louis-Camille Maillard discovered in 1912 that amino acids and sugars react to form brown compounds.
- Explain the conditions that speed the Maillard reaction: high temperature, dry surfaces and higher pH.
- Test the effect of pH on browning, and pan-sear pork chops to 145 °F with a 3-minute rest.

> **Warm-up.** Compare a slice of bread with a slice of toast, a boiled potato with a roasted one, or raw and toasted nuts (if no allergies). Write three words for the smell and taste of each browned food that you would not use for the pale one.

WATCH

Why the Maillard Reaction Makes Everything Delicious

Reactions · 2:54

https://www.youtube.com/watch?v=rs1JLYXROVU

> **WHEN TO WATCH**
> During session 1. Note the temperature range the narrator gives for fast browning and the three tips for making it work for you.

KEY TERMS

Maillard reaction

A complex set of reactions between amino acids and reducing sugars that forms brown pigments (melanoidins) and hundreds of flavor and aroma compounds.

reducing sugar

A sugar, such as glucose, fructose, lactose or maltose, with a reactive group that can bond with an amino acid. Sucrose is not a reducing sugar until it breaks down.

melanoidins

The brown, large molecules formed late in the Maillard reaction.

pH

A scale of acidity: below 7 is acidic, 7 neutral, above 7 basic (alkaline). Higher pH speeds the Maillard reaction.

searing

Browning the surface of food quickly in a very hot pan.

carryover cooking

The rise in internal temperature after food leaves the heat.

CORE IDEAS

The story. Louis-Camille Maillard was a French physician and chemist who studied how proteins form in living things. In 1912, working in Paris, he heated solutions of amino acids with sugars to see whether they would combine. They did, and something else happened: the mixtures turned yellow, then brown, gave off carbon dioxide and smelled of cooking. He reported the results to the French Academy of Sciences in 1912.

How they figured it out. Maillard used simple, controlled mixtures, a single amino acid such as glycine with a single sugar such as glucose, in water, heated for set times, and he watched for color and gas. He guessed that the reaction mattered for biology and for the browning of foods, but the chemistry was so complicated that it was largely forgotten until the 1940s and 1950s. Then food chemists trying to keep dried foods from turning brown and stale, including American soldiers' dried eggs and powdered milk, rediscovered it. In 1953 the chemist John Hodge published the first clear map of its steps.

The kitchen science. In the Maillard reaction an amino acid's amino group attacks a reducing sugar. A chain of rearrangements and breakdowns follows, producing hundreds of small molecules responsible for the flavors of toast, roasted coffee and chocolate, seared meat and fried onions, and finally large brown melanoidins. Which flavors form depends on which amino acids and sugars are present, so seared beef and toasted bread smell different. Three conditions speed it up. **Temperature:** it goes slowly at room temperature (which is why stored foods slowly brown) but rapidly above about 280–330 °F (140–165 °C). **Dryness:** water keeps a surface near 212 °F, so a wet surface steams instead of browning; pat meat dry. **pH:** a slightly basic surface browns faster, which is why pretzels are dipped in a baking-soda or lye

solution and a pinch of baking soda speeds the browning of onions. Caramelization (Lesson 3.2) is a different reaction: sugar alone, at higher temperatures.

Let's cook. You will sear pork chops in a heavy skillet and cook them to 145 °F (63 °C) with a 3-minute rest, the USDA safe temperature for whole cuts of pork. The skill is **searing**: a dry surface, a hot pan, and leaving the meat alone until the crust releases.

PICTURE STUDY



Louis-Camille Maillard, Unknown photographer, Early 20th century · Photograph · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Louis-Camille Maillard (1878–1936) taught and researched in Nancy, Paris and Algiers. He was trying to understand how the body builds proteins when he found the reaction that now carries his name in every food-science textbook.

Look closely

- Look at his clothing and expression. What kind of person does he seem to be?
- Imagine his laboratory bench: test tubes of glycine and glucose warming in a water bath. What color changes would he see?
- What would he have smelled as the tubes browned?

Talk about it

1. Maillard's discovery was ignored for decades before food chemists rediscovered it. Why might an important discovery be overlooked for so long?
2. Maillard studied simple mixtures, not steaks. Why is it useful to study a simplified version of a complicated process?
3. What everyday foods would taste completely different if the Maillard reaction did not happen?

> **Safety first.** Searing uses a very hot pan and a little oil: turn on the exhaust fan, keep a lid nearby, and lay the meat in the pan away from you. Pork chops must reach 145 °F (63 °C) with a 3-minute rest. Use a separate board and tongs for raw meat, and wash hands after handling it.

KITCHEN LAB

Does pH Change Browning?

Will a slightly basic surface brown faster than a neutral or acidic one? You will brush bread with three solutions, toast it identically, and compare. Then you will sear pork chops.

You will need

- Three slices of the same white sandwich bread
- Three small cups, a pastry brush, baking soda and lemon juice
- pH test strips
- A toaster oven or the oven broiler, and a timer
- A heavy 12-inch skillet (cast iron if you have it), tongs and an instant-read thermometer
- Your lab notebook

Pan-Seared Pork Chops

Serves 4 · Prep 10 min (plus 30 min salting) · Cook 10–14 min

Ingredients

- 4 boneless or bone-in pork chops, about 1 inch thick (about 1½ lb, 680 g)
- 1 teaspoon kosher salt and ½ teaspoon black pepper
- 1 tablespoon vegetable oil
- 2 tablespoons butter, 2 cloves garlic (smashed) and a few sprigs of thyme (optional)
- For the pan sauce: ½ cup chicken broth, 1 teaspoon Dijon mustard, 1 tablespoon lemon juice

Method

1. Pat the chops dry with paper towels and sprinkle with the salt and pepper. Let them sit uncovered in the refrigerator 30 minutes (the surface dries further).
2. Heat the oil in the skillet over medium-high heat until it shimmers.

3. Lay the chops in the pan, away from you. Cook without moving them 4–5 minutes until a deep brown crust forms and they release easily.
4. Turn and cook 3–5 minutes more. Add the butter, garlic and thyme for the last 2 minutes and spoon the foaming butter over the chops.
5. Remove when the thickest part reads about 140 °F; rest on a plate 3 minutes, when it should reach at least 145 °F (63 °C).
6. Pan sauce: pour off excess fat, add the broth to the hot pan and scrape up the brown bits (the fond), simmer 2 minutes, then whisk in the mustard and lemon juice. Spoon over the chops.
7. Wash the board, tongs and skillet; wipe the stove.

Allergy check: Contains milk (butter). For milk-free, use olive oil instead of butter. Dijon mustard is not a U.S. major allergen but can cause reactions; check your broth label.

Steps

1. **Prepare solutions.** In three cups mix ¼ cup water with: (A) nothing, (B) 1 tablespoon lemon juice, (C) ½ teaspoon baking soda. Measure and record the pH of each with a strip.
2. **Hypothesis.** Predict the order of browning from fastest to slowest and give a reason.
3. **Brush** one slice of bread evenly with each solution (same number of strokes), and label them.
4. **Toast** all three side by side on the same tray under the broiler or in the toaster oven for the same time, checking every 30 seconds until the darkest is deep golden.
5. **Compare.** Rank the color and photograph them together. Taste a corner of each and describe flavor and bitterness.
6. **Sear** the pork chops and record: pan temperature (if you have an infrared thermometer), the time until the crust released, the internal temperature off the heat and after resting, and the raw and cooked masses.
7. **Conclusion.** Explain your toast results with pH and the Maillard reaction, and explain why patting meat dry matters.
8. Clean up and sanitize everything that touched raw pork.

Tips

- A crowded pan steams instead of searing. Cook in two batches if the chops touch.
- Cast iron holds heat well, so the pan temperature drops less when the meat goes in.
- The brown bits stuck to the pan (fond) are concentrated Maillard flavor; dissolve them into the sauce.

Check your work

- ☐ I can explain the Maillard reaction and how temperature, moisture and pH affect it.
- ☐ I tested the effect of pH on browning.
- ☐ I seared pork chops and cooked them to 145 °F with a 3-minute rest.

LAB NOTEBOOK

1. Draw a simple scheme of the Maillard reaction: amino acid + reducing sugar → many flavor molecules → brown melanoidins, with the conditions that speed it.
2. Paste or draw the three toast slices with their pH values and browning ranks.
3. Record the pork chop data: times, temperatures, masses and yield.

KEY FORMULAS

$$[\mathrm{H}^+] = 10^{-\mathrm{pH}}$$

$$\text{rate ratio} \approx 2^{\Delta T/10\,^\circ\mathrm{C}}$$

From history. Maillard chemistry is also found inside the body: glucose slowly reacts with proteins in the blood, and doctors measure one product, hemoglobin A1c, to check long-term blood sugar in people with diabetes. Maillard's own guess that his reaction mattered for medicine turned out to be right.

WORKED EXAMPLES

Example 1. Lemon juice has a pH of about 2.3 and a baking-soda solution about 8.3. How many times more hydrogen ions does the lemon juice have?

Show solution

1. $\dfrac{10^{-2.3}}{10^{-8.3}} = 10^{6}$.

Answer: A million times more. Each pH unit is a factor of 10.

Example 2. If the Maillard reaction roughly doubles in rate for every 10 °C, how much faster does it go on a pan surface at 160 °C than inside a 100 °C boiling pot?

Show solution

1. $\Delta T = 60\ ^{\circ}\mathrm{C}$; $2^{60/10} = 2^{6} = 64$.

Answer: About 64 times faster, which is why boiled meat stays gray and seared meat browns.

Example 3. A 1-inch pork chop reads 138 °F when you take it off the heat. During a 3-minute rest it rises 6 °F. Is it safe, and what is its final temperature in °C?

Show solution

1. $138 + 6 = 144\ ^{\circ}\mathrm{F}$, just under 145 °F.
2. $\frac{5}{9}(144 - 32) = 62.2\ ^{\circ}\mathrm{C}$.

Answer: Not quite: 144 °F (62 °C). Return it to the pan for a minute so it reaches 145 °F after resting; next time take it off at about 140 °F.

Example 4. Four pork chops weigh 680 g raw and 540 g cooked. Find the cooking loss and the cooked yield percentage.

Show solution

1. Loss: $680 - 540 = 140$ g.
2. Yield: $\dfrac{540}{680} \times 100\% = 79\%$.

Answer: 140 g lost (mostly water and some fat), a 79% yield. Overcooking lowers the yield as proteins squeeze out more juice.

PRACTICE

1. Easy In what year did Maillard report the reaction of sugars and amino acids?

Show answer

1912.

2. Easy Why should meat be patted dry before searing?

Show answer

Surface water keeps the surface near 212 °F and makes steam, which prevents browning.

3. Easy What is the USDA safe temperature for whole cuts of pork?

Show answer

145 °F (63 °C) with a 3-minute rest.

4. Medium How many times more acidic is pH 4 than pH 6?

Show answer

$10^2 = 100$ times.

5. Medium Name two ways the Maillard reaction differs from caramelization.

Show answer

It needs amino acids as well as sugars; it happens at lower temperatures (and even slowly at room temperature).

6. Medium Why are pretzels dipped in a baking-soda bath before baking?

Show answer

The alkaline surface speeds the Maillard reaction, giving a deep brown, flavorful crust.

7. Medium Is sucrose a reducing sugar? What has to happen before it joins the Maillard reaction?

Show answer

No; it must first break down (hydrolyze) into glucose and fructose.

8. Medium Chops weigh 720 g raw and 590 g cooked. Find the cooked yield.

Show answer

$590/720 = 82\%$

9. Hard Using the doubling-per-10 °C rule, how much faster is browning at 150 °C than at 130 °C? At 180 °C than at 150 °C?

Show answer

4 times; 8 times.

10. Hard Dried eggs stored warm turned brown and stale during World War II. Explain why, and suggest two ways to prevent it.

Show answer

The Maillard reaction proceeds slowly even at storage temperatures between egg proteins and glucose. Remove the glucose before drying (food scientists used yeast or enzymes to do this) and store the powder cool and dry.

11. Challenge Boiled meat is gray but safe and tender; seared meat is brown and flavorful. Design a cooking method that gives both a tender interior and a brown crust, and explain the science.

Show answer

Sear first or last in a very hot, dry pan for the Maillard crust, and cook the interior gently (a moderate oven, or a braise) to the safe temperature without overcooking; the surface must be dry and above about 300 °F only briefly.

COMMON MISTAKES

- Moving the meat around before the crust forms, so it sticks and tears.
- Crowding the pan.
- Cooking pork to 160–170 °F out of old habit; whole cuts are safe at 145 °F with a rest and much juicier.
- Leaving the fond to burn instead of making a sauce.

> **Make it a game · Browning Detective.** Find five browned foods in the kitchen: toast, seared meat, crackers, onions, cookies. For each, decide whether Maillard, caramelization or both, and name the reducing sugar and amino acid involved. Predict whether a bit of baking soda would speed browning. Tell how Louis-Camille Maillard found it in 1912.

4.4 Gluten: Beccari's Sticky Discovery

OBJECTIVES

- Tell how Jacopo Beccari isolated gluten from wheat flour in Bologna in 1728.
- Explain how glutenin and gliadin form gluten, and how kneading, resting, hydration and fat affect it.
- Measure wet gluten from three flours and calculate baker's percentages for a pizza dough.

> **Warm-up.** Mix 2 tablespoons of flour with 1 tablespoon of water into a small ball and squeeze and stretch it for 2 minutes. How does it change? (Wash your hands afterward and do not taste raw dough.)

WATCH

Science: What is Gluten? Here's How to See and Feel Gluten

America's Test Kitchen · 3:24

https://www.youtube.com/watch?v=zDEcvSc2UKA

> **WHEN TO WATCH**
> During session 1. Watch the dough-washing demonstration carefully; you will do the same thing in the lab.

KEY TERMS

gluten
The stretchy protein network formed when wheat flour's glutenin and gliadin are mixed with water.

glutenin
Long, coiled wheat proteins that link into chains and give dough elasticity (spring back).

gliadin
Smaller wheat proteins that act like a lubricant between glutenin chains and give dough extensibility (stretch).

hydration
The mass of water in a dough as a percentage of the mass of flour.

baker's percentage

Each ingredient's mass as a percentage of the total flour mass, with flour as 100%.

windowpane test

Stretching a small piece of dough thin enough to see light through it without tearing, a sign of well-developed gluten.

CORE IDEAS

The story. In 1728 Jacopo Bartolomeo Beccari, a professor in Bologna, presented an experiment to the city's Academy of Sciences. He made a dough of wheat flour and water and then washed it under water, kneading it gently, until the milky starch was all rinsed away. What remained in his hands was a sticky, stretchy, grayish mass that behaved, he said, like animal matter rather than plant matter: it smelled and decomposed like flesh when it rotted. He had isolated gluten, and he was the first to show that wheat contains a large amount of a substance like those in meat.

How they figured it out. Beccari separated flour by a physical property: starch granules wash out in water, but the protein network holds together. His comparison with animal substances was a clue that would be confirmed a century later when chemists found that both gluten and meat are made of nitrogen-containing proteins.

The kitchen science. Wheat flour contains two families of storage proteins, **glutenin** and **gliadin**. Dry, they are separate. With water and mixing, they hydrate, uncoil and link through bonds between sulfur atoms (disulfide bonds) and many weaker bonds into a three-dimensional network: **gluten**. Glutenin gives the network elasticity; gliadin lets it stretch. Kneading aligns and strengthens the network; resting lets it relax so dough can be rolled without springing back. The network traps gas from yeast and steam, so bread can rise. Flour type sets the possible strength: bread flour has about 12–14% protein, all-purpose about 10–12%, cake flour about 7–9%. Fat and sugar coat proteins and limit gluten (tender cakes and crusts); water and time build it. Gluten is also the reason wheat, barley and rye must be avoided by people with celiac disease, an autoimmune reaction to gluten that only a doctor can diagnose.

Let's cook. You will make pizza from a dough designed with **baker's percentages**, the language bakers use to describe a dough by its ratios rather than a single batch size. The skill is **kneading to the windowpane**.

PICTURE STUDY



Woman Baking Bread, Jean-François Millet, 1854 · Oil on canvas · Kröller-Müller Museum, Otterlo, Netherlands

Image: Wikimedia Commons, public domain

Millet grew up on a farm in Normandy and painted the work of country households with great respect. Here a woman loads her week's bread into the family's wood-fired oven.

Look closely

- Find the peel (the long wooden paddle). Why use such a long handle?
- Look at the shaped loaves. How did the dough hold its shape before baking?
- Look at her arms and posture. What does kneading enough dough for a family's week require?
- Find the oven's mouth. What kinds of heat transfer bake the bread inside?

Talk about it

1. This family probably baked once a week. How would they keep the bread from going stale (Lesson 3.4)?
2. What would happen to the shaped loaves if the dough had been mixed but never kneaded?
3. Bread was the center of most meals in Millet's France. Why do you think "daily bread" appears in the Lord's Prayer?

> **Safety first.** Never taste raw dough. A pizza oven setting of 500 °F or a hot baking steel or stone is very hot: use long mitts and a peel or the back of a baking sheet, and slide pizzas in and out carefully. Families with a wheat allergy or celiac disease should skip the gluten-washing lab and make a gluten-free pizza crust.

KITCHEN LAB

Washing Out the Gluten

You will repeat Beccari's 1728 experiment with three flours, weigh the gluten each one gives, and stretch them to compare. Then you will make pizza with dough written in baker's percentages.

You will need

- Bread flour, all-purpose flour and cake flour
- A digital scale (0.1 g if possible), three small bowls and a fine sieve
- A timer
- A large bowl for the pizza dough and plastic wrap
- A baking sheet or pizza stone, a rolling pin (optional) and long oven mitts
- Your lab notebook

Homemade Pizza

Serves Two 12-inch pizzas (4–6 servings) · Prep 20 min · Rise 1½–2 hr · Bake 10–14 min each

Ingredients

- 500 g (about 4 cups) bread flour
- 325 g (1⅓ cups plus 1 tablespoon) warm water, about 100 °F (38 °C)
- 10 g (1¾ teaspoons) salt
- 4 g (1¼ teaspoons) instant yeast
- 15 g (1 tablespoon) olive oil, plus more for the bowl
- Toppings: 1½ cups pizza or crushed-tomato sauce, 225 g (8 oz) shredded mozzarella, and your choice of vegetables or cooked meats

Method

1. Stir the flour, yeast and salt in a large bowl. Add the water and oil and mix into a shaggy dough.
2. Knead on a lightly floured counter 8–10 minutes, until smooth and elastic and a small piece stretches into a thin "windowpane." Do not taste the dough.
3. Put it in an oiled bowl, cover, and let rise until doubled, 1½–2 hours.

4. Heat the oven to 500 °F (260 °C) with a rack in the lower third (and a pizza stone or upside-down baking sheet on it, if you have one) for at least 30 minutes.
5. Divide the dough in half. Stretch each piece into a 12-inch round on parchment. If it springs back, let it rest 10 minutes and try again.
6. Top with sauce, cheese and toppings. Slide the pizza, on its parchment, onto the hot stone or sheet. Bake 10–14 minutes until the crust is deep golden and the cheese bubbles.
7. Cool 3 minutes before slicing. Wash the bowl and counter; let the stone cool completely in the oven.

Allergy check: Contains wheat (gluten) and milk (mozzarella). Meat toppings may contain other allergens. For milk-free, skip the cheese or use a dairy-free cheese; for wheat-free, use a gluten-free pizza crust mix.

Steps

1. **Hypothesis.** Predict the order of gluten amount from the three flours and give a reason.
2. **Make three doughs.** For each flour, mix 50.0 g flour with 30 g water into a ball. Knead each for 2 minutes and let rest, covered, 20 minutes.
3. **Wash.** Hold one dough ball under a gentle stream of cool water over a sieve and squeeze and knead it until the water runs nearly clear, 5–10 minutes. Do the same for the others.
4. **Weigh** each gluten ball after gently squeezing out excess water. Calculate wet-gluten percentage.
5. **Stretch.** Stretch each ball slowly and compare how far it goes and how much it springs back. Then discard the gluten balls.
6. **Make the pizza dough** and calculate its baker's percentages. Perform the windowpane test before rising.
7. **Bake** the pizzas and serve.
8. **Conclusion.** Compare your gluten results with the protein content printed on each flour bag. Explain the stretch differences with glutenin and gliadin.
9. Clean up: wash bowls in cool water first (warm water makes dough gummy), then hot soapy water.

Tips

- If the dough is hard to stretch, it is the gluten fighting back. Cover it and let it rest; gluten relaxes with time.
- A hotter oven and preheated stone make a crisper crust because the bottom gets a burst of conducted heat.
- Too many wet toppings make a soggy center. Cook mushrooms and spinach first to drive off water.

Check your work

- ☐ I can explain how glutenin and gliadin form gluten and what kneading and resting do.
- ☐ I washed gluten from three flours and compared them by mass.
- ☐ I made pizza dough from baker's percentages and kneaded it to the windowpane stage.

LAB NOTEBOOK

1. Draw glutenin chains (coiled springs) and gliadin (small balls) before mixing, and the linked network after kneading.
2. Record the gluten-washing data in a table with the protein content from each flour bag.
3. Write the pizza dough as baker's percentages and scale it to three pizzas.

KEY FORMULAS

$$\text{baker's } \% = \frac{m_{\text{ingredient}}}{m_{\text{flour}}} \times 100\%$$

$$\text{wet gluten } \% = \frac{m_{\text{wet gluten}}}{m_{\text{flour}}} \times 100\%$$

From history. Gluten is used on its own too: "vital wheat gluten" strengthens whole-grain breads, and seitan, a high-protein food made from washed gluten, has been eaten in China and Japan for centuries.

WORKED EXAMPLES

Example 1. A pizza dough uses 500 g bread flour, 325 g water, 10 g salt, 4 g instant yeast and 15 g olive oil. Write its baker's percentages.

Show solution

1. Flour: 100%. Water: $\dfrac{325}{500} \times 100\% = 65\%$.
2. Salt: 2.0%; yeast: 0.8%; oil: 3.0%.

Answer: Flour 100%, water 65% (the hydration), salt 2%, yeast 0.8%, oil 3%.

Example 2. You want to make 1,200 g of total dough with the same percentages. How much flour do you need?

Show solution

1. Sum of percentages: $100 + 65 + 2 + 0.8 + 3 = 170.8\%$.
2. Flour: $\dfrac{1200\ \text{g}}{1.708} = 703\ \text{g}$.
3. Water: $0.65 \times 703 = 457$ g; salt 14 g; yeast 5.6 g; oil 21 g.

Answer: About 703 g flour, 457 g water, 14 g salt, 5.6 g yeast and 21 g oil.

Example 3. From 50 g of bread flour you wash out 18.0 g of wet gluten; from 50 g of cake flour, 9.5 g. Find each wet-gluten percentage.

Show solution

1. Bread flour: $\dfrac{18.0}{50} \times 100\% = 36\%$.
2. Cake flour: $\dfrac{9.5}{50} \times 100\% = 19\%$.

Answer: 36% and 19%. Wet gluten is about two-thirds water, so dry gluten is roughly a third of these values, close to each flour's protein content.

Example 4. A dough at 65% hydration feels too stiff. You have 500 g flour in it. How much more water would bring it to 70%?

Show solution

1. Water now: 325 g; at 70%: $0.70 \times 500 = 350$ g.
2. Add 25 g.

Answer: About 25 g (about 1½ tablespoons) more water.

PRACTICE

1. Easy In what year and city did Beccari isolate gluten?

   Show answer

   1728, Bologna.

2. Easy Name the two wheat proteins that form gluten.

   Show answer

   Glutenin and gliadin.

3. Easy A dough has 600 g flour and 420 g water. Find its hydration.

   Show answer

   70%.

4. Medium Which flour forms the most gluten: bread, all-purpose or cake? Why?

   Show answer

   Bread flour, because it has the most protein (about 12–14%).

5. Medium Why does pizza dough spring back after you stretch it, and what fixes it?

   Show answer

   The kneaded gluten is elastic; resting the dough lets the network relax.

6. Medium A recipe at 2% salt uses 750 g flour. How much salt?

   Show answer

   15 g

7. Medium Why do pie crust and cake recipes avoid much kneading?

Show answer

They should be tender; kneading builds gluten and makes them tough and chewy.

8. Medium Why must people with celiac disease avoid wheat, barley and rye?

Show answer

Their immune system reacts to gluten proteins (and related proteins in barley and rye), damaging the small intestine.

9. Hard A baker wants 6 pizzas at 280 g of dough each using 100% flour, 65% water, 2% salt, 0.8% yeast, 3% oil. Find the flour.

Show answer

Total 1680 g; $1680/1.708 = 984$ g.

10. Hard 50 g of a flour yields 15.6 g of wet gluten, which dries to 5.4 g. Estimate the flour's protein percentage and the water content of the wet gluten.

Show answer

About $5.4/50 = 10.8\%$ protein (all-purpose); water $10.2/15.6 = 65\%$.

11. Challenge Explain why adding 20% sugar (baker's percentage) to a dough weakens its gluten.

Show answer

Sugar is hygroscopic: it competes for the water that glutenin and gliadin need to hydrate and link, and it gets between the proteins, so less gluten forms.

COMMON MISTAKES

- Adding extra flour every time dough feels sticky, which lowers hydration and makes a dense crust.
- Fighting springy dough instead of letting it rest.
- Tasting raw dough.
- Washing gluten bowls in hot water first, which turns dough into glue.

Make it a game · Strong or Tender. Your parent calls out dough actions: more kneading, a long rest, more water, added oil, an overworked pie crust. You answer strong or tender, chewy or soft, and the cause in glutenin and gliadin terms. Twelve calls, all answered in five seconds. Tell how Jacopo Beccari washed gluten out of flour in 1728.

4.5 Collagen, Gelatin and the Slow Braise

OBJECTIVES

- Tell how Peter Cooper patented a method for making powdered gelatin in 1845, and how gelatin dessert became Jell-O in 1897.
- Explain the structure of meat (muscle fibers and collagen), and how long, moist cooking converts collagen to gelatin.
- Braise beef chuck, test tenderness over time, and show that the braising liquid gels when cold.

> **Warm-up.** Look at a package of beef chuck and a package of beef tenderloin or sirloin (or pictures). Which costs more per pound? Which do you think is tougher? Why might the cheaper one make a better stew?

WATCH

A Tasting of Culinary Science—Collagen

The Culinary Institute of America · 3:57

https://www.youtube.com/watch?v=Fb_NVHUl1b8

> **WHEN TO WATCH**
> During session 1. Note the temperature at which collagen begins to shrink and the conditions that turn it into gelatin.

KEY TERMS

muscle fiber

A long cell made of contractile proteins (myosin and actin); bundles of fibers make up meat.

collagen

The tough, rope-like connective-tissue protein, a triple helix, that wraps muscle fibers and makes up tendons.

gelatin

Collagen whose triple helix has unwound and broken into shorter strands; it dissolves in hot water and sets to a gel when cold.

braising

Browning meat, then cooking it slowly, partly covered in liquid, in a covered pot at a low simmer or in a low oven.

connective tissue

The collagen-rich tissue that holds muscles together; plentiful in hard-working muscles such as chuck, shank and shoulder.

CORE IDEAS

The story. Cooks have made gelatin since the Middle Ages by boiling calves' feet and bones for hours, skimming and clarifying the broth, and letting it set into jelly, a long and messy job. In 1845 the New York inventor and industrialist Peter Cooper, who also built the first American steam locomotive and founded Cooper Union, received a patent for a method of making powdered gelatin that could be stored and dissolved quickly. It did not become popular until 1897, when Pearle Wait, a carpenter in LeRoy, New York, added fruit flavors and his wife May named it Jell-O; a few years later it was one of America's best-known desserts.

How they figured it out. Every cook who made stock noticed that a pot of bones and tough meat simmered long enough would set into a jelly when cold. The science behind it took longer: in the 1950s scientists determined that collagen is a *triple helix*, three protein chains wound tightly together like a rope, and that heat in the presence of water unwinds it into gelatin.

The kitchen science. Meat is muscle: bundles of long fibers made of the proteins myosin and actin, wrapped in sheets of **collagen**. Muscles that work hard, like the shoulder (chuck), shank and brisket, have much more collagen than lightly used muscles like the tenderloin. That is why they are tough when cooked quickly and cheap at the store. Heat affects the two parts differently. The fiber proteins denature and squeeze out juice between about 140 and 170 °F, so lean tender cuts are best cooked quickly to a lower temperature. Collagen shrinks sharply around 140–150 °F, but in long, moist heat above about 160–180 °F its triple helix gradually unwinds and dissolves into **gelatin**, which makes the meat fall apart and gives the sauce a rich, silky body. This takes hours, which is why tough cuts are **braised**: browned for Maillard flavor, then simmered gently in a covered pot until a fork slides in easily, usually at an internal temperature around 195–205 °F. When the braising liquid chills, the gelatin re-forms loose helices and the liquid sets into a gel.

Let's cook. You will make a family beef stew from chuck, testing its tenderness at intervals, and then chill some of the liquid to see the gelatin set. The skill is **holding a low simmer**, with bubbles only lazily breaking the surface, for hours.

PICTURE STUDY



Peter Cooper, Unknown photographer, c. 1850s · Daguerreotype · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Peter Cooper (1791–1883) had only a year of formal schooling but became one of America's great inventors and businessmen. He founded Cooper Union in New York to give free education in science and art to working people.

Look closely

- Look at his face. How old do you think he is here?
- Early photographs needed the sitter to hold still for many seconds. How hard would that be with a small child on your lap?
- Look at his plain clothing. What does it suggest about him?

Talk about it

1. Cooper's gelatin patent made an old kitchen process quick and convenient. Can you think of another food that was made convenient by a new process?
2. Why was making gelatin from bones and hooves such a long job before powdered gelatin?
3. Cooper used his fortune to found a free school. What does that suggest about what he valued?

Safety first. Browning meat in hot oil spatters: pat it dry, add it a few pieces at a time with tongs, and keep a lid nearby. The Dutch oven and stew stay extremely hot for a long time; lift the lid away from you and use mitts. Cool leftovers quickly in shallow containers and refrigerate within 2 hours; reheat to 165 °F.

KITCHEN LAB

How Long Does Tough Become Tender?

How does braising time change the tenderness and yield of beef chuck? You will braise a stew, take out sample cubes each hour, and then show the gelatin in the cold liquid.

You will need

- A Dutch oven or heavy lidded pot
- A digital scale, an instant-read thermometer and a timer
- Tongs, a fork and a cutting board for raw meat
- Three small labeled cups and a small clear glass
- Your lab notebook

Beef Stew

Serves 6 · Prep 30 min · Cook 2½–3 hr

Ingredients

- 2½ lb (1.1 kg) beef chuck, cut into 1½-inch cubes
- 1½ teaspoons salt and ½ teaspoon pepper
- 3 tablespoons vegetable oil, divided
- 1 large onion, chopped; 3 cloves garlic, minced
- 2 tablespoons tomato paste and 3 tablespoons flour
- 4 cups (960 mL) beef broth
- 1 teaspoon dried thyme and 2 bay leaves
- 4 carrots, cut into 1-inch pieces
- 1½ lb (680 g) potatoes, cut into 1½-inch pieces
- 1 cup frozen peas and chopped parsley

Method

1. Pat the beef very dry and season with salt and pepper. Weigh and record its raw mass.

2. Heat 1 tablespoon oil in the Dutch oven over medium-high heat. Brown the beef in three batches, without crowding, 6–8 minutes per batch, adding oil as needed. Move it to a bowl.
3. Lower the heat to medium. Cook the onion 5 minutes, add the garlic and tomato paste and stir 1 minute, then stir in the flour for 1 minute.
4. Slowly whisk in the broth, scraping up the browned bits. Return the beef and its juices, add the thyme and bay leaves, and bring to a simmer.
5. Cover and cook at a bare simmer (or in a 325 °F / 165 °C oven) for 1½ hours, then add the carrots and potatoes and cook about 1 hour more, until the beef is fork-tender.
6. Stir in the peas for the last 5 minutes. Remove the bay leaves, taste for salt, and serve with parsley.
7. Cool leftovers in shallow containers and refrigerate within 2 hours. Wash the board and tongs used for raw beef with hot soapy water.

Allergy check: Contains wheat (flour). For wheat-free, thicken with 2 tablespoons cornstarch in a cold-water slurry stirred in near the end. Check your broth label.

Steps

1. **Hypothesis.** Predict how tenderness will change at 1, 2 and 3 hours, and why.
2. **Sample.** At 1 hour, 2 hours and the end of cooking, remove one cube of beef. Record its internal temperature, weigh it, and test it: how easily does a fork slide in? Rate 1 (very tough) to 5 (falls apart). Return the sampled cubes to the pot or set them aside for tasting once cooked through.
3. **Yield.** At the end, lift out all the beef with tongs, weigh it, and calculate the cooking yield. Return it to the pot.
4. **Gelatin test.** Spoon ½ cup of the strained liquid into a clear glass and refrigerate it overnight. Does it set? Tip the glass and describe it.
5. **Cost.** Use your receipt to calculate the cost of the stew per serving.
6. **Conclusion.** Explain the tenderness changes with collagen and gelatin, and why the meat was toughest at 1 hour.
7. Clean up and sanitize everything that touched raw beef.

Tips

- Brown in batches. Crowded meat steams and turns gray instead of browning.
- A low oven gives the most even, gentle heat for a braise.
- Stews taste even better the next day, after flavors blend; skim the solid fat from the top when cold.

Check your work

- ☐ I can explain the structure of meat and why some cuts are tough.
- ☐ I can explain how braising converts collagen to gelatin.
- ☐ I measured tenderness over time, calculated yield and cost, and showed gelatin setting.

LAB NOTEBOOK

1. Draw a piece of meat: muscle fibers in bundles wrapped by collagen sheets, and a close-up of collagen's triple helix unwinding into gelatin.
2. Record the tenderness ratings, temperatures and masses in a table, and graph tenderness against time.
3. Write the stew recipe in your own words with its cost per serving.

KEY FORMULAS

$$\text{cooking yield} = \frac{m_{\text{cooked}}}{m_{\text{raw}}} \times 100\%$$

$$\text{cost per serving} = \frac{\text{total cost}}{\text{servings}}$$

From history. Peter Cooper's locomotive, the Tom Thumb, raced a horse-drawn car on the Baltimore and Ohio Railroad in 1830. The horse won when the engine's belt slipped, but the railroad was convinced and bought steam locomotives. Cooper Union, which he founded in 1859, offered free tuition for most of its history.

WORKED EXAMPLES

Example 1. 2.5 lb (1,134 g) of chuck cubes weigh 760 g after braising. Find the cooking yield.

Show solution

1. $\dfrac{760}{1134} \times 100\% = 67\%$.

Answer: About 67%; a third of the raw mass was lost as water and fat, much of it into the sauce.

Example 2. Chuck costs \$6.49 per pound and tenderloin \$19.99 per pound. Find the cost of 2.5 lb of each, and the cost per serving of meat for 6 servings.

Show solution

1. Chuck: $2.5 \times \$6.49 = \$16.23$; per serving $\$16.23/6 = \$2.70$.
2. Tenderloin: $2.5 \times \$19.99 = \$49.98$; per serving \$8.33.

Answer: About \$2.70 per serving for chuck versus \$8.33 for tenderloin, about a third of the cost.

Example 3. A stew recipe adds the following costs to the meat: vegetables \$4.10, broth \$2.50, tomato paste and herbs \$1.40. Find the total cost and the cost per serving for 6.

Show solution

1. $\$16.23 + \$4.10 + \$2.50 + \$1.40 = \$24.23$.
2. $\dfrac{\$24.23}{6} = \$4.04$.

Answer: \$24.23 in all, about \$4.04 per serving.

Example 4. Gelatin sets a liquid firmly at about 2.5% by mass. A cup of chilled braising liquid (240 g) sets into a soft gel. Suppose it is about 1.5% gelatin. How many grams of collagen were converted to gelatin in that cup?

Show solution

1. $0.015 \times 240\ \text{g} = 3.6\ \text{g}$.

Answer: About 3.6 g of gelatin, from the collagen of the meat, in that one cup.

PRACTICE

1. Easy What protein makes connective tissue tough?

   Show answer

   Collagen.

2. Easy What does long, moist cooking turn collagen into?

   Show answer

   Gelatin.

3. Easy In what year did Peter Cooper patent powdered gelatin? When was Jell-O named?

   Show answer

   1845; 1897.

4. Medium Why is chuck cheaper and tougher than tenderloin?

   Show answer

   Chuck is a hard-working shoulder muscle with much more collagen; tenderloin does little work and has little collagen.

5. Medium Why should a tenderloin not be braised for three hours?

   Show answer

   It has little collagen to convert, so long cooking only squeezes the juice out of its fibers and dries it.

6. Medium 1,000 g of raw short ribs give 610 g cooked. Find the yield.

   Show answer

   61%

7. Medium Why does cold stew liquid become jelly-like?

Show answer

Dissolved gelatin re-forms loose helices and a network as it cools, trapping the water.

8. Medium A braise needs 3 hours at 200 °F inside the meat. Why can't a cook speed it up by boiling hard?

Show answer

The meat's fibers would tighten and squeeze out more juice, and collagen conversion depends on time at temperature; a hard boil also toughens the surface and clouds the sauce.

9. Hard A stew's ingredients cost $27.60 and it serves 8. A restaurant sells it for $14 a bowl. What percentage of the price is food cost?

Show answer

Per serving $\$3.45$; $3.45/14 = 24.6\%$.

10. Hard Fresh pineapple contains an enzyme, bromelain, that breaks proteins. Predict what happens if you add fresh pineapple to a gelatin dessert, and why canned pineapple works.

Show answer

The gelatin will not set, because bromelain cuts the gelatin chains. Canning heats the pineapple and denatures the enzyme.

11. Challenge Braised beef reaches 160 °F after 30 minutes but is still tough; at 2½ hours it is about 200 °F and tender. Explain why temperature alone does not predict tenderness for a braise.

Show answer

Collagen conversion is a slow process that depends on both temperature and time. At 160 °F the fibers have set and squeezed out juice, but little collagen has dissolved yet; hours above about 180 °F are needed to convert enough collagen to gelatin.

COMMON MISTAKES

- Boiling a stew hard instead of simmering it.
- Stopping when the meat reaches a "safe" temperature instead of when it is tender.

- Crowding the pan when browning.
- Leaving a big pot of stew to cool on the stove for hours.

> **Make it a game · Choose the Cut.** Your parent names a cut of meat: tenderloin, chuck roast, brisket, flank. You choose the cooking method, time and temperature direction, and explain with muscle fibers, collagen and gelatin. Do ten cuts. Then tell how Peter Cooper patented powdered gelatin in 1845 and how it became Jell-O.

UNIT 4

Proteins

Proteins are the most changeable molecules in the kitchen. Heat, acid, salt, air and even a whisk can unfold them, and once unfolded they bond to each other to set an egg, hold a foam, brown a crust, stretch a dough or turn a tough cut tender. In this unit you will learn how proteins are built from amino acids, how their shapes fold and unfold, and how cooks control those changes.

The stories follow Emil Fischer's first synthetic peptides, the investigators who found Salmonella inside clean eggs, Louis-Camille Maillard's browning tubes, Jacopo Beccari's washed dough and Peter Cooper's powdered gelatin. The labs measure foam overrun, egg-setting temperatures, browning and pH, wet gluten and braising tenderness, and the recipes are Swiss meringues, baked custard, seared pork chops, homemade pizza and beef stew.

PREREQUISITES

- Unit 1: calibrated thermometer and the USDA safe temperatures
- Unit 3: reducing sugars and caramelization
- Comfort searing and browning in a hot pan with a parent at home

MASTERY CHECKLIST

- ☐ I can describe amino acids, peptide bonds and the four levels of protein structure.
- ☐ I can explain denaturation and coagulation, egg-setting temperatures and why egg dishes are cooked to 160 °F.
- ☐ I can explain the Maillard reaction and how temperature, moisture and pH control it.
- ☐ I can explain how gluten forms and use baker's percentages.
- ☐ I can explain collagen, gelatin and why tough cuts are braised.
- ☐ I can calculate overrun, cooking yield, baker's percentages and cost per serving.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **King Arthur Baking: Baker's Percentage**: Free. A clear explanation of baker's percentages with examples, for Lesson 4.4.
- **A heavy cast-iron skillet**: Optional. Holds heat for searing (Lesson 4.3) and is useful all year. Any heavy skillet works.
- **A Dutch oven or heavy lidded pot**: Used for the braise in Lesson 4.5 and the bread in Unit 6. A heavy stockpot with a lid works for the stew.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

4.1 Amino Acids, Protein Structure and Foam: Emil Fischer's Peptides
3 sessions of 50–90 minutes (plus 2 hours of baking)

4.2 Denaturation, Custard and the 160 °F Egg Line — 3 sessions of 50–90 minutes

4.3 The Maillard Reaction: Louis-Camille Maillard's Brown Crust
3 sessions of 50–90 minutes

4.4 Gluten: Beccari's Sticky Discovery — 3 sessions of 50–90 minutes (plus rising time)

4.5 Collagen, Gelatin and the Slow Braise
3 sessions of 50–90 minutes (plus 2½–3 hours of braising)

Unit 4 Test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **5 pts**
   What did Emil Fischer propose about the structure of proteins around 1902?

2. **6 pts**

   Draw or describe what happens when two amino acids join, and name the bond and the by-product.

3. **6 pts**

   80 mL of egg whites whip to 600 mL. Find the overrun, and explain why a trace of yolk would lower it.

4. **6 pts**

   Explain why sugar and cream of tartar each make a more stable foam.

5. **7 pts**

   Give the approximate setting temperatures of egg white (start), yolk, and a stirred custard, and explain why a custard sets higher.

6. **5 pts**

   Why must egg dishes reach 160 °F, even with clean uncracked eggs?

7. **6 pts**

   Scale a custard of 4 eggs, 600 mL milk and 90 g sugar to serve 15 instead of 6.

8. **6 pts**

   Name three conditions that speed the Maillard reaction and give a kitchen example of each.

9. **6 pts**

   How many times more basic (fewer H^+ ions) is a solution at pH 8.5 than one at pH 5.5?

10. **6 pts**

    Pork chops read 139 °F off the heat and rise 7 °F while resting 3 minutes. Are they safe? Convert the final temperature to °C.

11. **6 pts**

    Name the two proteins that form gluten and what each contributes.

12. **7 pts**

    Write the baker’s percentages for 800 g flour, 560 g water, 16 g salt and 6 g yeast, and find the flour for 2,000 g of the same dough.

13. **5 pts**

    Describe Beccari’s 1728 experiment.

14. **6 pts**

    Explain why chuck is braised while tenderloin is seared.

15. **7 pts**

    1,400 g of raw chuck costing $6.80 per pound becomes 940 g cooked. Find the yield, and the cost per 100 g of cooked meat (1 lb = 454 g).

16. **10 pts**

    Short essay (5–7 sentences): A cook makes a beef stew. Explain the protein science of each stage: drying and browning the meat, simmering for an hour, simmering for three hours, and chilling the leftover liquid.

ANSWER KEY

1. That proteins are long chains of amino acids joined by peptide bonds; he built short chains in the laboratory to test it.
2. The carboxyl group of one and the amino group of the other join with loss of a water molecule, forming a peptide bond.
3. $(600 - 80)/80 = 650\%$. Yolk fat gets between unfolded proteins at the bubble walls and prevents them bonding.
4. Sugar dissolves into the bubble walls and thickens them, slowing drainage; acid (cream of tartar) helps proteins bond in a stable way and makes the foam harder to over-whip.
5. White starts about 140–145 °F, yolk about 158 °F, custard about 170–180 °F. Milk dilutes the proteins and sugar gets between them, so more heat is needed before they bond.
6. Salmonella Enteritidis can be inside the egg; 160 °F destroys it.
7. Factor 2.5: 10 eggs, 1,500 mL milk, 225 g sugar.
8. High temperature (searing at 300+ °F); dry surface (patting meat dry); higher pH (baking-soda bath for pretzels).
9. $10^3 = 1000$ times.
10. Yes, 146 °F; $\frac{5}{9}(114) = 63.3\ ^\circ\text{C}$.
11. Glutenin (elasticity, spring back) and gliadin (extensibility, stretch).
12. 100%, 70%, 2%, 0.75%; total 172.75%; $2000/1.7275 = 1158$ g flour.
13. He washed a flour-and-water dough under water until the starch rinsed away, leaving a sticky, stretchy protein mass (gluten) that behaved like animal substances.
14. Chuck is rich in collagen, which needs long moist heat to become gelatin; tenderloin has little collagen and is best cooked quickly to a lower temperature so its fibers stay juicy.
15. Yield 67%; cost $(1400/454)(6.80) = \$20.97$, per 100 g cooked $\$2.23$.
16. Answers vary. Full credit for: a dry surface and high heat give the Maillard reaction; after an hour, fiber proteins have denatured and squeezed out juice but collagen is still largely intact, so meat is tough; after three hours, collagen has unwound into gelatin and the meat is tender; chilled, the gelatin re-forms a network and the liquid sets.

UNIT PROJECT: THE EGG INVESTIGATION

Eggs show almost every protein behavior in this unit: foaming, setting, emulsifying, browning. Design and carry out a two-part investigation. Part 1: a controlled experiment on one variable of an egg dish (for example, the effect of milk-to-egg ratio on custard firmness, sugar timing on meringue stability, or acid on poached-egg shape), with at least two trials each and a measurement.

Part 2: write a one-page illustrated explanation, for a younger cook, of what happens to egg proteins in five different egg dishes your family eats, including the safe temperature for each. Serve the best result of your experiment at a family breakfast or dessert.

LOOK FOR	WHAT IT MEANS
Safety	All egg dishes eaten were cooked to 160 °F or used pasteurized eggs; raw eggs handled with clean-up and sanitizing.
Experimental design	One variable, controlled conditions, replicated trials, a real measurement.
Science explanation	Correct use of denaturation, coagulation, foams and the Maillard reaction in your own words.
Data and calculations	Clear table, correct calculations (overrun, ratios, temperatures) with units.
Communication	The one-page explanation is accurate, clear and helpful to a younger cook.

UNIT 5

Fats and Emulsions

Fats carry flavor, transfer heat, make pastry tender and flaky, and with the help of emulsifiers hold oil and water together in sauces and dressings. In this unit you will learn the chemistry of fats and oils from fatty acids to triglycerides, why some are solid and others liquid, how they behave in a hot pan, how emulsions form and break, and how fat and steam build a flaky crust.

The stories run from Chevreul's fatty acids and David Wesson's refined oil to Gobley's lecithin, Wilhelm Normann's hydrogenation and Crisco, and Mège-Mouriès's margarine. You will churn butter, measure oil temperature and absorption in shallow frying, time the separation of vinaigrettes, compare cold and soft fat in pastry, and measure the water in butter and spreads. The recipes are biscuits with homemade butter, crispy chicken cutlets, a chopped salad with honey-mustard vinaigrette, apple hand pies and shortbread.

PREREQUISITES

- Unit 2: polarity, hydrogen bonds, $q = mc\Delta T$
- Unit 4: gluten formation and baker's percentages
- Has used the stove and oven safely; a parent present for shallow frying

MASTERY CHECKLIST

- ☐ I can describe triglycerides and saturated, unsaturated and trans fatty acids, and relate structure to melting point.
- ☐ I can explain smoke point and oil temperature in frying, and fry safely without deep frying.
- ☐ I can explain emulsions and emulsifiers and make a stable vinaigrette.
- ☐ I can explain how fat makes pastry tender and flaky, and the history of hydrogenation and trans fats.
- ☐ I can compare butter, margarine and spreads and explain their behavior in baking.
- ☐ I can calculate yields, ratios, droplet surface area, steam volume and fat and water percentages.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FDA: Trans Fat**: Free. The FDA's explanation of trans fat and the removal of partially hydrogenated oils, for Lesson 5.4.
- **King Arthur Baking: Pie Crust Guide**: Free. Step-by-step photographs for mixing, rolling and crimping pie dough.
- **A clip-on frying thermometer**: Optional. Makes the shallow-frying lab in Lesson 5.2 easier and safer; an instant-read thermometer that reads to 400 °F also works.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

5.1	**Fatty Acids and Butter: Chevreul's Fats**	3 sessions of 50–90 minutes
5.2	**Smoke Points and Shallow Frying: David Wesson's Oil**	3 sessions of 50–90 minutes
5.3	**Emulsions and Emulsifiers: Gobley's Lecithin**	3 sessions of 50–90 minutes
5.4	**Shortening and Flakiness: Crisco and the Pie Crust**	3 sessions of 50–90 minutes
5.5	**Mège-Mouriès and Margarine**	3 sessions of 50–90 minutes

Unit 5 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   What did Chevreul show about fats in 1823, and how?

2. **6 pts**
   Explain why butter is solid at room temperature but olive oil is liquid.

3. **6 pts**
   Find the theoretical butter yield from 720 g of cream at 38% fat if butter is 81% fat. If you get 310 g, find the percent yield.

4. **5 pts**

   Linolenic acid is $C_{18}H_{30}O_2$. How many double bonds does it have? Explain.

5. **6 pts**

   Define smoke point and explain why refined oils have higher smoke points.

6. **7 pts**

   300 g of oil at 180 °C (c = 2.0 J/(g·°C)) receives 100 g of food at 10 °C (c = 3.0). Ignoring the burner, find the mixed temperature. Why is this an argument against crowding the pan?

7. **5 pts**

   Give two safety rules for shallow frying.

8. **6 pts**

   Explain how an emulsifier stabilizes an oil-in-water emulsion, and name two kitchen emulsifiers.

9. **6 pts**

   1 mL of oil is divided into droplets of radius 0.0010 cm. How many droplets, and what total surface area?

10. **5 pts**

    Make 300 mL of a 3 : 1 vinaigrette.

11. **7 pts**

    Explain both the tenderness and the flakiness of a good pie crust.

12. **6 pts**

    What is hydrogenation, and why were partially hydrogenated oils removed from U.S. foods?

13. **5 pts**

    How much steam at 100 °C can the water in 200 g of butter (16% water) make?

14. **6 pts**

    Why did Napoleon III offer a prize for a butter substitute, and what did Mège-Mouriès make it from?

15. **6 pts**

A spread has 8 g of fat per 14 g serving. Find its fat percentage and say whether it can be legally sold as margarine in the U.S.

16. **12 pts**

Short essay (5–7 sentences): Choose butter, a vinaigrette or mayonnaise. Explain what kind of emulsion it is, what keeps it together, what can make it break, and how a cook prevents or fixes that.

ANSWER KEY

1. That fats are compounds of glycerol and fatty acids; he split fats with alkali (as in soapmaking) and purified and characterized the fatty acids.
2. Butter is rich in saturated fatty acids with straight chains that pack tightly; olive oil is rich in cis-unsaturated fatty acids whose kinks keep them from packing.
3. $273.6/0.81 = 338$ g; $310/338 = 92\%$.
4. Three; it has 6 fewer hydrogens than stearic acid ($C_{18}H_{36}O_2$), and each double bond removes 2 H.
5. The temperature of continuous smoke as oil breaks down; refining removes free fatty acids and particles that break down at lower temperatures.
6. $600(180 - T) = 300(T - 10)$; $T = 123\ ^\circ\text{C}$. A large load drops the oil far below frying temperature, so food absorbs oil and gets soggy.
7. Any two: parent present; no more than ¼–½ inch of oil; lay food in away from you; lid and baking soda nearby; never water on a grease fire; turn off heat if oil smokes.
8. Its oil-loving tail enters the droplet and its water-loving head faces the water, coating droplets so they do not merge. Lecithin (egg yolk) and mustard.
9. One droplet 4.19×10^{-9} cm^3; 2.4×10^8 droplets; area each 1.26×10^{-5} cm^2, total 3.0×10^3 cm^2.
10. 225 mL oil, 75 mL vinegar.
11. Tender: fat coats flour, limiting gluten. Flaky: flat pieces of cold fat separate dough layers; in the oven the fat melts and its water and the dough's water turn to steam that lifts the layers apart.
12. Adding hydrogen to the double bonds of unsaturated oils with a catalyst to make them more solid. Partial hydrogenation makes trans fats, which raise heart-disease risk; the FDA removed them (determination 2015, by 2018).
13. $32\ \text{g} \times 1.7\ \text{L/g} = 54\ \text{L}$
14. Butter was costly and spoiled; the army, navy and poor needed a cheap fat that kept. He used the soft fraction (oleo) of beef fat, churned with milk and water.
15. 57%; no, margarine must be at least 80% fat, so it is a spread.
16. Answers vary. Full credit for correctly identifying the emulsion type (butter water-in-oil; vinaigrette and mayonnaise oil-in-water), naming the emulsifier or

structure, naming a cause of breaking (heat, too much oil too fast, temperature, too little emulsifier) and a correct remedy.

UNIT PROJECT: THE FAT LAB REPORT

Choose one question about fats in your family's cooking and answer it with a controlled experiment: for example, does butter, shortening or a blend make the flakiest pie crust; which oil makes the crispest shallow-fried potatoes at the same temperature; or which emulsifier makes the most stable homemade dressing over a week?

Run at least two trials of each treatment, measure something real (thickness and layers, oil absorbed, separation height, a blind taste-panel score), and write a full lab report with a graph. Include a one-paragraph explanation of the fat chemistry involved and a note on safety. Serve the winning version to your family.

LOOK FOR	WHAT IT MEANS
Safety	Hot oil handled only with a parent present, no deep frying, fire safety ready; cleanup complete.
Experimental design	One variable, controls named, at least two trials each, a real measurement.
Data and graph	Clear table with units; appropriate graph with labeled axes.
Fat chemistry	Correct explanation using fatty acids, melting, smoke point, emulsions or steam.
Conclusion	Answers the question honestly from the data, with sources of error and an improvement.

5.1 Fatty Acids and Butter: Chevreul's Fats

OBJECTIVES

- Tell how Michel-Eugène Chevreul showed in 1823 that fats are made of glycerol and fatty acids.
- Explain saturated and unsaturated fatty acids and how their shapes set the melting points of butter, coconut oil and olive oil.
- Churn butter from cream, calculate its yield, and bake buttermilk biscuits with it.

> **Warm-up.** Put a spoonful each of butter, coconut oil and olive oil (and any other fat in your kitchen) in small cups in the refrigerator for an hour. Which ones turn solid? Which stay liquid? Write a guess about why.

WATCH

Saturated fats, unsaturated fats, and trans fats | Biology | Khan Academy

Khan Academy · 8:56

https://www.youtube.com/watch?v=O9lL2KStW9s

> **WHEN TO WATCH**
> During session 1. Draw the shapes of a saturated, a cis-unsaturated and a trans fatty acid as the video draws them.

BACKUP VIDEO

The science behind butter | Make your own butter from cream

Abbey the Food Scientist · 9:54

https://www.youtube.com/watch?v=59eVS8sZx0k

Before the churning lab. A food scientist explains phase inversion: how cream (fat in water) becomes butter (water in fat).

KEY TERMS

triglyceride

The main molecule of fats and oils: one glycerol joined to three fatty acids.

fatty acid

A long chain of carbon atoms with hydrogens attached and an acid group at one end.

saturated

A fatty acid with only single bonds between carbons, so it holds as many hydrogens as possible and is straight; saturated fats tend to be solid at room temperature.

unsaturated

A fatty acid with one (mono-) or more (poly-) carbon–carbon double bonds. Natural double bonds are usually cis, which kink the chain so oils stay liquid.

phase inversion

An emulsion turning inside out, as when churning turns cream (fat droplets in water) into butter (water droplets in fat).

CORE IDEAS

The story. Michel-Eugène Chevreul was a French chemist who lived to be 102 and worked for most of the nineteenth century. Early in his career he took on a messy, unglamorous subject: animal fats and soap. In 1823, after about ten years of work, he published *Chemical Researches on Fats of Animal Origin*.

How they figured it out. Soapmakers had long boiled fat with lye to make soap. Chevreul studied what happened chemically. He showed that the lye split fat into two parts: a sweet, syrupy substance, glycerol, and a set of acids that formed the soap. He separated and purified these acids, measured their melting points, and named several, including stearic acid (from the Greek for tallow), oleic acid (from olive oil) and butyric acid (from butter, the source of rancid butter's smell). Fats, he concluded, are compounds of glycerol and fatty acids. His work turned soap and candle making into a science, and it later made margarine possible (Lesson 5.5).

The kitchen science. A fat molecule is a **triglyceride**: glycerol with three fatty acids. A **saturated** fatty acid is a straight zigzag chain; straight chains stack neatly like pencils, so fats rich in them (butter, lard, coconut oil) are solid at room temperature. A **cis double bond** puts a kink in the chain, so unsaturated fats (olive, canola, sunflower oils) pack loosely and stay liquid. Most fats are mixtures, so they melt over a range: butter softens around 60–70 °F and melts fully near 90–95 °F, just below body temperature, which is why it melts on the tongue. Cream is an emulsion of tiny fat droplets, each wrapped in a membrane, in water. Shaking or churning cold cream batters the droplets until their membranes break and partly solid fat globules clump

together, trapping air (whipped cream) and then sticking into grains of butter as the watery buttermilk splashes free. The result has turned inside out: butter is about 80–82% fat with tiny droplets of water (about 16%) dispersed in it.

Let's cook. You will churn cream into butter in a jar and use it, with buttermilk, in a batch of biscuits. The skill is **keeping fat cold**: cold butter cut into flour leaves flat pieces that turn to steam and make biscuits flaky (more in Lesson 5.4).

PICTURE STUDY



Woman Churning Butter, Jean-François Millet, c. 1855–1856 · Etching · Museum of Fine Arts, Boston

Image: Wikimedia Commons, public domain

Millet drew the work of French farm households many times. Churning was a regular, tiring task: cream skimmed from several days' milk was worked in a tall wooden churn until the butter came.

Look closely

- Find the churn and the plunger (the dasher). How does pushing it up and down make butter?
- Look at her posture. How long do you think churning took?
- Find the cat. Why might a cat hang around a dairy?
- Find the shelf and pans behind her. What were shallow pans used for in a dairy?

Talk about it

1. Churners said the butter "came" suddenly after a long time of nothing happening. Use phase inversion to explain why.
2. Dairies were kept cool, often in a stone room or near a spring. Why does temperature matter for churning?
3. What would a farm family do with the buttermilk left after churning?

> **Safety first.** Hold the jar firmly with both hands and a towel while shaking; a slippery jar can fall and break (or use a sturdy plastic jar). Wash the butter in cold water so it keeps longer, and refrigerate it. The biscuits bake at 450 °F: use mitts.

KITCHEN LAB

Making Butter and Measuring Yield

You will churn cream into butter, measure the theoretical and actual yields, compare the melting of different fats, and bake biscuits with your butter.

You will need

- A clean 1-quart jar with a tight lid (or a stand mixer)
- A digital scale, a fine sieve and a bowl of ice water
- Small cups of butter, coconut oil, olive oil and vegetable shortening
- A thermometer and a bowl of warm water
- A pastry cutter or two knives, a baking sheet
- Your lab notebook

Homemade Butter and Buttermilk Biscuits

Serves About 10 biscuits (and about ¾ cup butter) · Churn 10–20 min · Prep 15 min · Bake 12–14 min

Ingredients

- **Butter:** 480 mL (2 cups) cold heavy cream (at least 36% fat), and ¼ teaspoon salt (optional)
- **Biscuits:** 250 g (2 cups) all-purpose flour
- 1 tablespoon baking powder, ½ teaspoon baking soda, 1 teaspoon salt, 1 teaspoon sugar
- 85 g (6 tablespoons) cold butter (your homemade butter or store-bought), cut into small pieces
- 240 mL (1 cup) cold buttermilk (store-bought cultured buttermilk, or the liquid from churning mixed with 1 tablespoon lemon juice)

Method

1. **Butter:** Pour the cold cream into the jar (no more than half full), close it tightly, and shake hard. It will become whipped cream, then seem to stop, then suddenly separate into yellow butter and thin liquid (10–20 minutes).

2. Pour off and save the liquid. Rinse the butter in ice water, pressing it with a spoon, until the water stays clear. Work in the salt if you like. Weigh it and refrigerate.
3. **Biscuits:** Heat the oven to 450 °F (230 °C). Whisk the flour, baking powder, soda, salt and sugar in a bowl.
4. Cut the cold butter into the flour until the largest pieces are the size of peas.
5. Stir in the buttermilk just until a shaggy dough forms. Turn it onto a floured counter, pat it 1 inch thick, fold it in half, and pat again. Repeat twice.
6. Cut 2½-inch rounds straight down (do not twist) and set them touching on the baking sheet. Bake 12–14 minutes until tall and golden.
7. Wash the jar, sieve and bowls in hot soapy water.

Allergy check: Contains milk (cream, butter and buttermilk) and wheat. There is no simple milk-free swap for churned butter; for milk-free biscuits use cold vegetable shortening and a plant milk with 1 tablespoon lemon juice.

Steps

1. **Prediction.** Calculate the theoretical butter yield from your cream's mass and fat percentage (on the label).
2. **Churn** the cream, timing each stage: liquid, soft whipped, stiff whipped, "break" (butter appears).
3. **Weigh** the washed butter and the buttermilk. Find the percent yield.
4. **Melting race.** Take the four fats from the refrigerator, set the cups in the same bowl of 85 °F (29 °C) water, and record the order in which they melt completely.
5. **Bake** the biscuits.
6. **Conclusion.** Explain the melting order with saturated and unsaturated fatty acids, and explain the sudden "break" in churning with phase inversion.
7. Clean up: hot soapy water for every buttery surface.

Tips

- Cream at about 55–60 °F (13–16 °C) churns fastest; very cold cream takes longer, and warm cream makes greasy butter.

- Washing out all the buttermilk helps homemade butter keep a week or two in the refrigerator.
- For tall biscuits, keep everything cold and handle the dough as little as possible.

Check your work

- ☐ I can explain triglycerides and saturated and unsaturated fatty acids.
- ☐ I can explain why butter and oils melt at different temperatures.
- ☐ I churned butter, calculated its yield, and baked biscuits with it.

LAB NOTEBOOK

1. Draw a triglyceride: glycerol with three fatty-acid tails, one saturated (straight) and one cis-unsaturated (kinked).
2. Draw cream (fat droplets in water) and butter (water droplets in fat) side by side.
3. Record churning times, masses, yield and the melting-race order.

KEY FORMULAS

$$\text{max butter} = \frac{m_{\text{cream}} \times x_{\text{fat, cream}}}{x_{\text{fat, butter}}}$$

$$\text{yield \%} = \frac{\text{actual}}{\text{theoretical}} \times 100\%$$

From history. Chevreul also studied color for the Gobelins tapestry works in Paris, and his book on how colors affect each other influenced the Impressionist painters. When he turned 100 in 1886, France celebrated with a national holiday-like jubilee and a medal.

WORKED EXAMPLES

Example 1. 480 g of heavy cream is 36% fat. If butter is 81% fat and all the fat ends up in the butter, what is the theoretical yield of butter?

Show solution

1. Fat: $0.36 \times 480\ \text{g} = 172.8\ \text{g}$.
2. Butter: $\dfrac{172.8\ \text{g}}{0.81} = 213\ \text{g}$.

Answer: About 213 g of butter at most.

Example 2. You actually collect 196 g of butter. Find the percent yield and suggest where the rest went.

Show solution

1. $\dfrac{196}{213} \times 100\% = 92\%$.

Answer: 92%. Some fat stays in the buttermilk and some butter sticks to the jar and spoon.

Example 3. Stearic acid is $C_{18}H_{36}O_2$; oleic acid is $C_{18}H_{34}O_2$. Use the formulas to find how many double bonds oleic acid has, and the molar mass of each.

Show solution

1. Oleic acid has 2 fewer hydrogens; each C=C double bond removes 2 H, so it has one double bond.
2. Stearic: $18(12.01) + 36(1.008) + 2(16.00) = 284.5$ g/mol. Oleic: 282.5 g/mol.

Answer: One double bond; 284.5 and 282.5 g/mol. That one kink lowers the melting point from about 69 °C (stearic) to about 13 °C (oleic).

Example 4. Fat supplies about 9 kcal per gram of food energy. How much energy is in one 14-g tablespoon of butter (81% fat)? Compare with one tablespoon of olive oil (14 g, 100% fat).

Show solution

1. Butter: $0.81 \times 14\ \text{g} \times 9\ \frac{\text{kcal}}{\text{g}} = 102$ kcal.
2. Olive oil: $14 \times 9 = 126$ kcal.

Answer: About 102 and 126 kcal: butter has less fat per tablespoon because about a fifth of it is water.

PRACTICE

1. Easy What two kinds of molecules did Chevreul show make up fats?

   Show answer

   Glycerol and fatty acids.

2. **Easy** Why are oils with many double bonds usually liquid at room temperature?

Show answer

The cis double bonds kink the chains so they cannot pack tightly.

3. **Easy** Butter is about what percent fat? What is most of the rest?

Show answer

About 80–82% fat; most of the rest is water.

4. **Medium** Find the theoretical butter yield from 1,000 g of cream at 40% fat, if butter is 82% fat.

Show answer

$400 / 0.82 = 488$ g

5. **Medium** You obtain 440 g from the cream in problem 4. Find the percent yield.

Show answer

$440 / 488 = 90\%$

6. **Medium** Linoleic acid is $C_{18}H_{32}O_2$. How many double bonds does it have? (Stearic is $C_{18}H_{36}O_2$.)

Show answer

Two (4 fewer hydrogens).

7. **Medium** Why does butter melt pleasantly in the mouth while lard can feel waxy?

Show answer

Butter melts fully just below body temperature; lard and shortening have fats with higher melting points.

8. **Medium** What is phase inversion in butter making?

Show answer

Cream is fat droplets in water; churning breaks and joins the fat until it becomes butter, water droplets in fat.

9. Hard Using 9 kcal/g, find the food energy in 100 g of olive oil and 100 g of butter (81% fat; ignore its tiny protein and sugar).

Show answer

900 kcal and about 729 kcal.

10. Hard Coconut oil is mostly saturated but melts at about 76 °F, lower than many saturated fats. Its fatty acids are mostly 12 carbons long. Suggest why it melts lower than beef tallow (mostly 16–18 carbons).

Show answer

Shorter chains have fewer contacts with their neighbors, so less energy is needed to pull them apart; it melts at a lower temperature.

11. Challenge Why does whipping cream need to be cold, while churning butter goes fastest a little warmer (55–60 °F)?

Show answer

Whipped cream needs partly solid fat globules to hold air bubbles in a stable network; at slightly warmer temperatures more fat is liquid, so globules merge (coalesce) faster into butter grains, which is what churning wants.

COMMON MISTAKES

- Filling the jar too full, so the cream cannot slosh.
- Leaving buttermilk in homemade butter, which makes it spoil fast.
- Using warm butter in biscuits, which melts into the flour instead of making flaky layers.
- Twisting the biscuit cutter, which seals the edges and stops the rise.

> **Make it a game · Fat Shapes.** Make a deck of cards with fats and fatty acid facts: butter, olive oil, coconut oil, saturated, unsaturated, solid at room temperature, kinked chain, straight chain. Match each fat to its structure and melting behavior in memory-style play. Explain phase inversion. Tell how Chevreul showed fats are glycerol and fatty acids.

5.2 Smoke Points and Shallow Frying: David Wesson's Oil

OBJECTIVES

- Tell how David Wesson's 1899 deodorizing process turned cottonseed oil into a clear, mild cooking oil.
- Explain smoke point, why refined oils smoke at higher temperatures, and how oil temperature affects frying.
- Shallow-fry breaded chicken cutlets, measuring oil temperature drop and oil absorption.

> **Warm-up.** Read the labels on the oils in your kitchen. Which say "refined," "extra virgin," or "high heat"? Arrange them in the order you think they would start smoking in a hot pan.

WATCH

All About Cooking With Vegetable Oils

America's Test Kitchen · 2:20

https://www.youtube.com/watch?v=tM-oo3_6uf8

> **WHEN TO WATCH**
> During session 1. Note which oils the test-kitchen expert recommends for high-heat cooking and why; look for the Wesson bottle from this lesson's story.

KEY TERMS

smoke point

The temperature at which an oil begins to give off a continuous stream of visible smoke as it starts to break down.

refined oil

Oil that has been purified (neutralized, bleached, deodorized) to remove free fatty acids and small particles, raising its smoke point and making its flavor mild.

free fatty acids

Fatty acids broken off their glycerol; they lower an oil's smoke point.

shallow frying

Cooking food in about ¼–½ inch of hot oil, turning it once. Deep frying (food submerged) is not done in this course.

flash point

The much higher temperature at which an oil's vapors can ignite. Long before then, smoke is the warning to turn down the heat.

CORE IDEAS

The story. In the 1800s cottonseed was mostly a waste product of the cotton industry, and the oil pressed from it was dark and strong-smelling. The chemist David Wesson developed a process to bleach and deodorize it by heating the oil under vacuum with steam, removing the compounds that gave it color, odor and flavor. In 1899 his clear, mild "Wesson Oil" went on sale, one of the first refined vegetable oils sold for American home cooking.

How they figured it out. Wesson knew that the unpleasant smells came from small, volatile molecules and from free fatty acids. Heating the oil in a vacuum let those molecules boil off at a lower temperature than they would in air, without damaging the oil itself. The refined oil not only tasted cleaner; it could also be heated much hotter before smoking.

The kitchen science. As oil is heated it eventually begins to break down: triglycerides split, free fatty acids and glycerol form, and glycerol breaks into acrolein, an irritating smoke. That is the **smoke point**. Refining removes free fatty acids and small particles, so refined oils smoke at higher temperatures: refined peanut, canola or avocado oil around 400–500 °F, extra-virgin olive oil and butter around 320–400 °F (butter is lower because of its milk solids; clarified butter is higher). Each time oil is heated and reused, its free fatty acids rise and its smoke point falls. For shallow frying, oil at about 350–375 °F (175–190 °C) cooks the surface fast: water at the surface of the food boils away as steam, which keeps oil from soaking in and makes a crisp crust. Oil that is too cool lets the food sit and absorb oil and turn greasy; too hot burns the crust before the inside is done. Food dropped in lowers the oil temperature, so frying in batches keeps it in range.

Let's cook. You will shallow-fry breaded chicken cutlets in a ¼-inch layer of oil, with a parent present. The skill is **managing oil temperature** with a thermometer: heat to 360 °F, fry a few pieces at a time, and let the oil recover between batches.

PICTURE STUDY



Women Picking Olives, Vincent van Gogh, 1889 · Oil on canvas · The Metropolitan Museum of Art, New York

Image: Wikimedia Commons, public domain

In the south of France, Van Gogh painted the olive harvest in late autumn. The olives were pressed for oil, the oldest cooking oil of the Mediterranean world, mentioned all through the Bible.

Look closely

- Find the woman on the ladder. How are the olives gathered?
- Look at the colors of the leaves and the ground. What season is it?
- Look at the swirling brushstrokes. How do they make the trees seem alive?
- Find the basket or cloth for the olives. What would happen to the olives next?

Talk about it

1. Olive oil pressed from fresh olives without heat or refining is “extra virgin.” Why does it smoke at a lower temperature than refined oils?
2. Olive oil was used in lamps, medicine and cooking in Bible times. Can you think of a passage that mentions it?
3. Why do you think Van Gogh painted the harvest so many times?

Safety first. Shallow-fry only with a parent present: use no more than ¼–½ inch of oil in a heavy, deep-sided skillet on a back burner, keep the handle turned in, lay food in away from you, and keep a lid and baking soda within reach. If the oil smokes, turn off the heat. Never add water to hot oil. Chicken must reach 165 °F (74 °C). Let used oil cool completely before straining or discarding it in a sealed container (not down the drain).

KITCHEN LAB

Temperature, Crispness and Oil Absorption

How much does adding food lower the oil temperature, and how much oil does fried food absorb? You will shallow-fry cutlets in two batches, logging oil temperature and weighing the pan and the food.

You will need

- A heavy 12-inch skillet with tall sides and a lid
- A clip-on or instant-read thermometer that reads to 400 °F
- A digital scale that can weigh the skillet
- Three shallow dishes for breading, tongs and a wire rack set on a sheet pan
- Long oven mitts and a box of baking soda by the stove
- Your lab notebook

Crispy Chicken Cutlets

Serves 4 · Prep 25 min · Fry 15 min

Ingredients

- 1¼ lb (570 g) boneless chicken breasts, sliced horizontally into 4 thin cutlets and pounded ½ inch thick
- 1 teaspoon salt and ½ teaspoon pepper
- ½ cup (65 g) all-purpose flour
- 2 large eggs beaten with 1 tablespoon water
- 1½ cups (90 g) panko breadcrumbs mixed with ¼ cup grated parmesan (optional)
- About 1 cup (240 mL) canola or peanut oil for a ¼-inch layer
- Lemon wedges for serving

Method

1. Pat the cutlets dry and season with salt and pepper. Set up three dishes: flour, egg, panko. Coat each cutlet in flour, then egg, then panko, pressing gently. Set them on a rack. Wash your hands.

2. Weigh the skillet with the oil and record it. Heat the oil over medium heat to 360 °F (182 °C).
3. Lay 2 cutlets in the oil, away from you. Fry 3–4 minutes per side until deep golden and the thickest part reads 165 °F (74 °C). Adjust the heat to keep the oil between 325 and 375 °F.
4. Move the cutlets to the rack (not paper towels, which make the bottoms steam). Let the oil return to 360 °F before frying the next batch.
5. Turn off the heat. Serve with lemon wedges.
6. When the oil is completely cool, weigh the skillet again. Pour the oil into a sealed container for the trash. Wash the dishes, tongs and anything that touched raw chicken.

Allergy check: Contains wheat (flour, panko), eggs and milk (if using parmesan); peanut if you fry in peanut oil (highly refined peanut oil is often tolerated, but check with your doctor). For wheat-free, use rice flour and gluten-free crumbs.

Steps

1. **Hypothesis.** Predict how far the oil temperature will drop when two cutlets go in, and how long it will take to recover.
2. **Weigh** the breaded cutlets before frying (record each batch's mass).
3. **Log temperature.** Record the oil temperature just before the first batch goes in and every 30 seconds until the batch comes out.
4. **Weigh** the cooked cutlets. After the oil cools, weigh the skillet again.
5. **Analyze.** Graph oil temperature against time for each batch. Calculate oil absorbed and water lost.
6. **Taste test.** Compare crispness of the first and second batches. Did the second batch go into oil at the same temperature?
7. **Conclusion.** Explain the temperature drop with $q = mc\Delta T$ and how the escaping steam keeps oil out of food.
8. Clean up carefully: cool oil completely before handling it.

Tips

- Pounding cutlets to an even thickness lets them cook through before the crust overbrowns.

- Wet hand, dry hand: use one hand for flour and panko and the other for egg, so your fingers do not get coated.
- If the crust browns before the center reaches 165 °F, lower the heat and cover for a minute, or finish the cutlets in a 375 °F oven.

Check your work

- ☐ I can explain smoke point and why refined oils can be heated hotter.
- ☐ I can explain why oil temperature matters in frying and calculate the effect of adding food.
- ☐ I shallow-fried safely with a parent present and measured oil absorption.

LAB NOTEBOOK

1. Make a smoke-point chart for the oils in your kitchen (°F and °C) from their labels or the lesson, and mark the shallow-frying range.
2. Graph your oil-temperature log for both batches.
3. Draw a cutlet in hot oil showing steam bubbling out of the crust and oil staying outside.

KEY FORMULAS

$$m_f c_f (T_f - T_{\text{mix}}) = m_o c_o (T_{\text{mix}} - T_o)$$

$$\text{oil absorbed} = m_{\text{oil, before}} - m_{\text{oil, after}}$$

From history. Crisco (Lesson 5.4) was first made from cottonseed oil. Today most American vegetable oil comes from soybeans and canola; canola was bred in Canada in the 1970s from rapeseed to be low in erucic acid, and its name comes from "Canada" and "oil."

WORKED EXAMPLES

Example 1. 400 g of oil at 180 °C (c = 2.0 J/(g·°C)) receives 300 g of cold breaded chicken at 5 °C (take c = 3.0 J/(g·°C)). Estimate the temperature after the heat is shared, ignoring the burner and evaporation.

Show solution

1. Heat lost by oil = heat gained by chicken: $(400)(2.0)(180 - T) = (300)(3.0)(T - 5)$.
2. $144{,}000 - 800T = 900T - 4{,}500$
3. $148{,}500 = 1700T \;\Rightarrow\; T = 87\ ^\circ\text{C}$.

Answer: About 87 °C in this simple model, a huge drop. Real oil drops less (perhaps to 140–150 °C) because the burner keeps adding heat and the chicken only gradually takes heat in, but the model shows why you must not crowd the pan.

Example 2. Before frying, the skillet and oil weigh 1,245 g; after frying four cutlets, 1,198 g. The cutlets weighed 520 g raw and breaded and 470 g cooked. How much oil was absorbed, and how much water was lost?

Show solution

1. Oil used (absorbed by food plus any spattered): $1245 - 1198 = 47$ g.
2. The food lost $520 - 470 = 50$ g, but gained about 47 g of oil, so it lost about $50 + 47 = 97$ g of water as steam.

Answer: About 47 g of oil absorbed and 97 g of water evaporated.

Example 3. Convert the smoke points 410 °F (refined canola) and 350 °F (butter) to Celsius.

Show solution

1. $\frac{5}{9}(410 - 32) = 210\ ^\circ\text{C}$; $\frac{5}{9}(350 - 32) = 177\ ^\circ\text{C}$.

Answer: About 210 °C and 177 °C. Butter alone burns at shallow-frying temperatures; cooks mix it with oil or clarify it.

Example 4. The 47 g of oil absorbed by four cutlets supplies how much food energy per cutlet at 9 kcal per gram?

Show solution

1. $\dfrac{47\ \text{g} \times 9\ \text{kcal/g}}{4} = 106\ \text{kcal}.$

Answer: About 106 kcal of energy from oil per cutlet. Frying at the right temperature keeps absorption low and the crust crisp.

PRACTICE

1. Easy What is the smoke point of an oil?

   Show answer

   The temperature at which it begins to give off continuous visible smoke as it breaks down.

2. Easy What temperature range is used for shallow frying?

   Show answer

   About 350–375 °F (175–190 °C).

3. Easy Should you put out a smoking or flaming pan of oil with water?

   Show answer

   No; turn off the heat and cover it with a lid. Never water.

4. Medium Why does refined oil have a higher smoke point than unrefined oil?

   Show answer

   Refining removes free fatty acids and small particles that break down and smoke at lower temperatures.

5. Medium Why does reused frying oil smoke sooner?

   Show answer

   Heating breaks triglycerides into free fatty acids and other products, which lower the smoke point.

6. Medium Convert 375 °F to Celsius.

   Show answer

   190.6 °C

7. Medium Why does food fried in oil that is too cool turn out greasy?

Show answer

The surface does not quickly turn its water to steam and crisp, so the food sits longer and absorbs more oil.

8. Medium A pan weighs 980 g with oil before frying and 951 g after. How much oil did the food absorb?

Show answer

29 g

9. Hard Using the model in Worked Example 1, find the temperature if only 150 g of chicken goes into the 400 g of oil.

Show answer

$(400)(2)(180 - T) = (150)(3)(T - 5)$ gives $T = 117\ ^\circ\text{C}$. Smaller batches lower the temperature much less.

10. Hard Why does butter burn at shallow-frying temperatures, while clarified butter does not?

Show answer

Butter's milk solids (proteins and sugar) brown and burn around 250–350 °F; clarifying removes them, leaving nearly pure fat with a smoke point near 450 °F.

11. Challenge Cotton is grown mainly for its fiber. Explain why Wesson's process was valuable both to cooks and to farmers.

Show answer

It turned a near-waste by-product (cottonseed) into a valuable, mild, high-smoke-point oil, giving farmers a market for seed and cooks a cheap neutral oil.

COMMON MISTAKES

- Crowding the pan, which drops the oil temperature and makes soggy, greasy food.
- Heating oil until it smokes before adding food.
- Draining fried food on paper towels instead of a rack.
- Pouring oil down the sink, where it clogs pipes.

> **Make it a game · Smoke Point Rank.** Write six oils from your kitchen on slips. Predict their ranking from lowest to highest smoke point, then check what you can from labels or your lesson. Explain why refining raises smoke point and what free fatty acids do. Fewest misplaced oils wins. Tell how David Wesson's deodorizing made a mild oil.

5.3 Emulsions and Emulsifiers: Gobley's Lecithin

OBJECTIVES

- Tell how Théodore Gobley isolated lecithin from egg yolk in the 1840s.
- Explain emulsions (oil-in-water and water-in-oil) and how emulsifiers such as lecithin and mustard stabilize them.
- Compare the stability of three vinaigrettes over time, and calculate how dividing oil into droplets multiplies its surface area.

> **Warm-up.** Shake oil and vinegar together in a jar and time how long until the layers separate. Now add a small spoonful of mustard and shake again. What changed?

WATCH

The Science of Food: Emulsions

Houston Museum of Natural Science · 4:19

https://www.youtube.com/watch?v=cuPpVQ14320

> **WHEN TO WATCH**
> During session 1. Watch how the egg yolk and mustard change the dressing, and listen for the word "emulsifier."

KEY TERMS

emulsion

A mixture of two liquids that do not dissolve in each other, with one dispersed as tiny droplets in the other.

oil-in-water emulsion

Oil droplets dispersed in water, such as milk, mayonnaise and vinaigrette.

water-in-oil emulsion

Water droplets dispersed in fat, such as butter and margarine.

emulsifier

A molecule with a water-loving (hydrophilic) end and a fat-loving (hydrophobic) end that coats droplets and keeps them from merging.

lecithin

A family of phospholipids found in egg yolk and soybeans; a natural emulsifier.

coalescence

Droplets merging into larger ones, the first step toward an emulsion separating (breaking).

CORE IDEAS

The story. Théodore Gobley was a Paris pharmacist and chemist who spent years analyzing egg yolk, the food that makes sauces like mayonnaise and hollandaise possible. In 1846 he described a fatty substance from yolk that contained phosphorus, and in 1850 he named it *lécithine*, from the Greek *lekithos*, egg yolk. He later found the same substance in brain tissue, fish eggs and blood.

How they figured it out. Gobley separated yolk into fractions with solvents and analyzed each, finding that one fraction contained not only fatty acids and glycerol but also phosphoric acid and a nitrogen compound. That unusual combination, a fat with a charged, water-loving "head," is exactly what makes lecithin an emulsifier, though it took decades more for chemists to understand why.

The kitchen science. Oil and water do not mix because water molecules attract each other through hydrogen bonds and squeeze nonpolar oil out (Lesson 2.1). Shaking breaks one liquid into droplets inside the other, an **emulsion**, but without help the droplets soon merge (**coalescence**) and the oil floats to the top. An **emulsifier** has a water-loving end and an oil-loving end; it lines up at the surface of each droplet with its oil-loving tail in the oil and its head in the water, forming a coat that keeps droplets apart. Lecithin in egg yolk does this, as do the mucilage and proteins in mustard seed. Thickeners (honey, mustard solids, starch) also help by slowing the movement of droplets. Smaller droplets make a thicker, creamier, more stable emulsion; that is why whisking hard or blending matters. Mayonnaise is about 70–80% oil held as droplets in a small amount of water and yolk; vinaigrette is usually about 3 parts oil to 1 part vinegar.

Let's cook. You will make a mustard-honey vinaigrette and a large chopped salad. The skill is **building an emulsion**: combine the vinegar and emulsifiers first, then add the oil slowly while whisking (or shake in a jar).

PICTURE STUDY



Kitchen Scene with Christ in the House of Martha and Mary, Diego Velázquez, 1618 · Oil on canvas · National Gallery, London

Image: Wikimedia Commons, public domain

Velázquez painted this when he was only about nineteen. In the front, a kitchen maid prepares a meal; in the background, the scene from Luke 10, where Martha is busy serving while her sister Mary sits at Jesus' feet listening.

Look closely

- Find the mortar and pestle. Garlic pounded with oil in a mortar makes a thick sauce like allioli, one of the oldest emulsions. What is she pounding?
- Find the eggs, the fish and the garlic. Which ingredient could help hold oil and water together?
- Look at the young woman's expression. How does she seem to feel about her work?
- Find the scene in the background. Who is sitting and who is standing?

Talk about it

1. Jesus told Martha that Mary had chosen "that good part." Was Martha's cooking wrong? How can serving and listening both be good?
2. Why might a cook pound garlic before adding oil, rather than just chopping it?

3. Why do you think Velázquez put the kitchen in the front and the Bible scene in the back?

Safety first. This lab uses no heat. Wash vegetables under running water and chop on a board with a damp towel underneath, using the claw grip. Raw-egg mayonnaise is not made in this course; if your family makes mayonnaise, use pasteurized eggs.

KITCHEN LAB

How Long Does an Emulsion Last?

Which emulsifiers keep a vinaigrette from separating longest? You will make three dressings that differ only in their emulsifier, shake them identically and measure how fast they separate.

You will need

- Three identical clear jars with lids
- Measuring spoons and cups
- A ruler and a timer
- A large bowl, a chef's knife and a cutting board
- Your lab notebook

Honey-Mustard Vinaigrette with a Chopped Salad

Serves 6 · Prep 25 min

Ingredients

- **Vinaigrette:** 60 mL (¼ cup) apple cider vinegar or lemon juice
- 1 tablespoon Dijon mustard
- 1 tablespoon honey
- 1 small clove garlic, finely minced, and ½ teaspoon salt, ¼ teaspoon pepper
- 180 mL (¾ cup) olive oil
- **Salad:** 1 large head romaine, chopped
- 1 cucumber, 1 bell pepper and 2 carrots, diced or shredded
- 1 cup cherry tomatoes, halved
- 1 can (15 oz) chickpeas, rinsed and drained
- ½ cup crumbled feta or shredded cheddar (optional)

Method

1. Wash all the vegetables under running water and dry them.

2. In a jar, combine the vinegar, mustard, honey, garlic, salt and pepper and shake (or whisk in a bowl).
3. Add the oil and shake hard for 30 seconds (or whisk it in slowly in a thin stream) until thick and creamy.
4. Chop the salad vegetables into bite-size pieces of about the same size and toss them in a large bowl with the chickpeas and cheese.
5. Shake the dressing again, pour on about two-thirds, toss, and add more to taste.
6. Refrigerate leftover dressing up to a week; it may thicken (olive oil firms in the cold), so let it warm 10 minutes and shake.

Allergy check: Contains milk if you add cheese. Honey is never given to babies under one year. Dijon mustard is not a U.S. major allergen but can cause reactions.

Steps

1. **Hypothesis.** Predict which jar will stay mixed longest: (A) oil and vinegar only, (B) plus 1 teaspoon mustard, (C) plus 1 teaspoon mustard and 1 teaspoon honey.
2. **Prepare.** In each jar put 45 mL (3 tablespoons) oil and 15 mL (1 tablespoon) vinegar, then the additions. Mark the liquid height on the outside with tape.
3. **Shake** each jar exactly 30 times, set them side by side and start the timer.
4. **Measure** the height of the clear vinegar layer at the bottom every 2 minutes for 20 minutes, then at 30 and 60 minutes.
5. **Graph** separated-layer height against time for all three.
6. **Make** the full vinaigrette and salad for the family.
7. **Conclusion.** Explain the results with emulsifiers and thickeners. Calculate how the surface area of the oil changes when droplets are made smaller.
8. Clean up: wash jars in hot soapy water.

Tips

- Dressing clings to dry leaves; wet leaves water it down and make it slide off.
- If a whisked emulsion breaks, start over with a fresh spoonful of mustard and slowly whisk the broken dressing into it.

- Dress a salad just before serving; salt and vinegar wilt leaves by drawing out water.

Check your work

- ☐ I can explain what an emulsion and an emulsifier are, with examples of each type.
- ☐ I measured the stability of three emulsions over time.
- ☐ I calculated droplet numbers and surface area.

LAB NOTEBOOK

1. Draw an oil droplet in vinegar coated with emulsifier molecules (heads out, tails in).
2. Graph your separation data.
3. List five emulsions in your kitchen and say whether each is oil-in-water or water-in-oil.

KEY FORMULAS

$$V_{\text{drop}} = \tfrac{4}{3}\pi r^3 \qquad A_{\text{drop}} = 4\pi r^2$$

$$\text{number of droplets} = \frac{V_{\text{total}}}{V_{\text{drop}}}$$

From history. Most lecithin used in foods today comes from soybeans and sunflower seeds. It is added to chocolate to make it flow smoothly when melted, to baking sprays, and to many other foods. Commercial lecithin from soy must be labeled with the soy allergen.

WORKED EXAMPLES

Example 1. A vinaigrette uses oil and vinegar in a 3 : 1 ratio by volume. How much of each for 1 cup (240 mL) of dressing?

Show solution

1. Total parts: 4. One part $= \dfrac{240\ \text{mL}}{4} = 60\ \text{mL}$.
2. Oil $3 \times 60 = 180\ \text{mL}$; vinegar 60 mL.

Answer: 180 mL (¾ cup) oil and 60 mL (¼ cup) vinegar.

Example 2. 1.0 mL (1.0 cm^3) of oil is broken into droplets 2.0 μm across ($r = 1.0 \times 10^{-4}$ cm). How many droplets form, and what is their total surface area?

Show solution

1. Volume of one droplet: $\frac{4}{3}\pi(1.0 \times 10^{-4})^3 = 4.19 \times 10^{-12}\ \text{cm}^3$.
2. Number: $\dfrac{1.0}{4.19 \times 10^{-12}} = 2.4 \times 10^{11}$.
3. Area of one: $4\pi(1.0 \times 10^{-4})^2 = 1.26 \times 10^{-7}\ \text{cm}^2$; total $(2.4 \times 10^{11})(1.26 \times 10^{-7}) = 3.0 \times 10^{4}\ \text{cm}^2$.

Answer: About 240 billion droplets with a total surface of about 30,000 cm^2, or 3 m^2, from one milliliter of oil. Every bit of that surface needs emulsifier to coat it.

Example 3. A mayonnaise has 220 g oil, 18 g yolk (about half water), 15 g lemon juice and 5 g mustard. Find the oil percentage by mass.

Show solution

1. Total: $220 + 18 + 15 + 5 = 258$ g.
2. $\dfrac{220}{258} \times 100\% = 85\%$.

Answer: About 85% oil, held as droplets in only about 30 g of water: a crowded, very thick emulsion.

PRACTICE

1. Easy Name an oil-in-water emulsion and a water-in-oil emulsion.

   Show answer

   Oil-in-water: milk, mayonnaise, vinaigrette. Water-in-oil: butter, margarine.

2. Easy What emulsifier is found in egg yolk?

   Show answer

   Lecithin.

3. Easy Make 120 mL of a 3 : 1 vinaigrette.

   Show answer

   90 mL oil and 30 mL vinegar.

4. Medium Explain how an emulsifier molecule keeps droplets apart.

Show answer

Its oil-loving tail sits in the oil droplet and its water-loving head in the water, forming a coat on each droplet so droplets cannot merge easily.

5. Medium Why does honey help a vinaigrette stay mixed even though it is not an emulsifier?

Show answer

It thickens the water phase, slowing the movement of droplets so they meet and merge less often.

6. Medium What did Gobley find in egg yolk, and what does the name lecithin mean?

Show answer

A phosphorus-containing fat (a phospholipid); from the Greek for egg yolk.

7. Medium A dressing is 200 mL oil and 50 mL vinegar. What is the ratio, and what percent is oil?

Show answer

4 : 1; 80% oil.

8. Medium Why must oil be added slowly when whisking mayonnaise or vinaigrette by hand?

Show answer

So it can be broken into small droplets and coated with emulsifier as it goes in; too much at once forms large droplets that merge and the emulsion breaks.

9. Hard If droplets are made 10 times smaller in diameter, by what factor does the total surface area of the same volume of oil change?

Show answer

It increases 10 times.

10. Hard A mayonnaise has 300 g oil and 40 g of water-phase ingredients. What percent oil is it, and why can it be so thick?

Show answer

$300/340 = 88\%$. The tightly packed oil droplets press against each other and cannot flow past one another easily.

11. Challenge Milk is an emulsion that does not separate quickly in the carton, but raw milk left standing forms a cream layer. Explain both, using droplet size and homogenization.

Show answer

Raw milk's fat globules are large enough to float up, forming cream. Homogenization forces milk through tiny openings, breaking globules into very small droplets coated with milk proteins; they rise so slowly that they stay mixed.

COMMON MISTAKES

- Adding all the oil at once when whisking by hand.
- Dressing salad greens while they are still wet.
- Thinking a separated dressing has spoiled; it just needs to be shaken.
- Making mayonnaise with raw, unpasteurized eggs.

Make it a game · Shake and Time. Shake a jar of oil and vinegar for ten seconds and time how long before it separates. Predict how long it lasts with a teaspoon of mustard, then test it. Record both in seconds and explain the role of lecithin as an emulsifier. Beat your record with a second recipe. Tell how Gobley found lecithin in egg yolk.

Scripture. "Martha, Martha, thou art careful and troubled about many things: But one thing is needful: and Mary hath chosen that good part, which shall not be taken away from her." (Luke 10:41-42, KJV)

Cooking for others is good work, and Velázquez painted it with honor. Jesus reminded busy Martha that listening to Him is the one thing most needful.

5.4 Shortening and Flakiness: Crisco and the Pie Crust

OBJECTIVES

- Tell how Wilhelm Normann's hydrogenation process (1902) led to Crisco shortening in 1911, and why partially hydrogenated oils were later removed from American foods.
- Explain how solid fat shortens gluten strands and how flat pieces of cold fat and steam make flaky layers.
- Compare crusts made with cold and with soft butter, and bake apple hand pies.

> **Warm-up.** Break a store-bought cracker, a piece of shortbread and a flaky croissant or biscuit (or look at pictures). How is each one built? Which has layers? What do you think made them?

WATCH

How to make pie crust

King Arthur Baking Company · 2:37

https://www.youtube.com/watch?v=iPY6u0cqZSk

> **WHEN TO WATCH**
> Before the lab. Watch how the baker leaves some butter in larger flattened pieces and adds ice water a little at a time.

BACKUP VIDEO

4 Tips for Failproof Pie Dough

King Arthur Baking Company · 6:16

https://www.youtube.com/watch?v=D281_-wvjGg

After your first crust. Four practical tips from a King Arthur instructor for crust that rolls without cracking.

KEY TERMS

shortening

Any solid fat used to make baked goods tender; also the name of solid vegetable fats like Crisco. Fat "shortens" gluten strands by coating flour.

hydrogenation

Adding hydrogen to unsaturated oils with a nickel catalyst, turning double bonds into single bonds and making the oil more solid.

trans fat

A fat with a trans double bond, formed in partial hydrogenation; it raises heart-disease risk, and partially hydrogenated oils were removed from the U.S. food supply after 2018.

lamination

Layers of dough separated by layers of fat; in the oven the fat melts and its water turns to steam, puffing the layers apart.

tender vs. flaky

Tender: little gluten, short crumbly texture. Flaky: thin crisp layers separated by air.

CORE IDEAS

The story. In 1902 the German chemist Wilhelm Normann patented a way to harden liquid oils by bubbling hydrogen gas through them in the presence of a nickel catalyst. The process turned cheap vegetable oil into a white, solid fat that looked and worked like lard. Procter & Gamble bought rights to the process for cottonseed oil and in 1911 introduced Crisco (from "crystallized cottonseed oil"), selling it with free cookbooks and cooking demonstrations as a modern alternative to lard and butter.

How they figured it out. Chemists knew the difference between solid fats and liquid oils was hydrogen: saturated fats carry more of it. Normann found the right catalyst and conditions to add it. But partial hydrogenation left some double bonds turned into the straight *trans* form. By the 1990s research had shown that trans fats raise LDL cholesterol and the risk of heart disease. Trans fat appeared on the Nutrition Facts label from 2006, and the FDA determined in 2015 that partially hydrogenated oils were no longer "generally recognized as safe"; they were removed from the U.S.

food supply by 2018. Today's shortenings are made in other ways (by blending fully hydrogenated and liquid oils, or with palm oil) and contain little or no trans fat. This is how science should work: a careful new study can correct an old assumption.

The kitchen science. Fat does two jobs in pastry. First, it **shortens**: fat worked into flour coats the flour particles so less water reaches them and less gluten forms, making the pastry tender. Second, if some pieces of fat stay cold and are flattened into thin sheets between layers of dough, they make it **flaky**: in a hot oven the fat melts, its water (butter is about 16% water) and the water in the dough turn to steam, and the steam pushes the layers apart before the starch and proteins set. The more solid and cold the fat, the more distinct the layers. Butter gives the best flavor but softens quickly; shortening stays solid over a wider temperature range and is easier to handle. Overmixing or warm fat makes a tough or greasy crust; too little water makes it crumble.

Let's cook. You will make an all-butter pie dough and use it to bake apple hand pies, comparing a crust made with cold butter to one made with soft butter. The skill is **keeping pastry cold** and handling it lightly.

PICTURE STUDY



The Faro Caudill Family Eating Dinner in Their Dugout, Pie Town, New Mexico, Russell Lee, for the Farm Security Administration, October 1940 · Photograph · Library of Congress, Washington, D.C.
Image: Wikimedia Commons, public domain

Pie Town, New Mexico, got its name in the 1920s from a roadside store whose owner baked pies, often from dried apples, for travelers. In 1940 Russell Lee photographed the homesteading families there, who grew and preserved most of their own food.

Look closely

- Find the table and the food. What can you identify?
- Find the jars and the pitcher on the table. What might they hold?
- Look at the walls of the dugout. How is this home built?
- Look at the faces of the family. What do they tell you about their life?

Talk about it

1. A dried-apple pie could be made in winter, far from any orchard. What fat do you think a homestead pie crust used: butter, lard or shortening? Why?
2. These families canned and dried food to last the year. How does that connect to Unit 8?
3. What does a shared meal at a small table in a hard place teach about hospitality and thankfulness?

> **Safety first.** Pastry work is cold, but the oven is 400 °F: use mitts and let hand pies cool 15 minutes before eating, since the filling is much hotter than the crust. Never taste raw dough. Cut apples on a stable board with the claw grip.

KITCHEN LAB

Cold Fat vs. Soft Fat

Does the temperature of the butter change how flaky a crust is? You will make two half batches of dough, one with cold butter and one with soft, room-temperature butter, and compare the baked layers.

You will need

- A digital scale, two bowls and a pastry cutter (or two knives)
- A rolling pin, a ruler and a 4-inch round cutter or a small bowl to trace
- Two baking sheets lined with parchment
- Plastic wrap and a refrigerator
- A small knife or fork for crimping
- Your lab notebook

Apple Hand Pies with All-Butter Crust

Serves About 10 hand pies · Prep 40 min · Chill 1 hr · Bake 20–25 min

Ingredients

- **Crust:** 190 g (1½ cups) all-purpose flour
- 1 teaspoon sugar and ½ teaspoon (3 g) salt
- 140 g (10 tablespoons) very cold butter, cut into ½-inch cubes
- 60–90 g (4–6 tablespoons) ice water
- **Filling:** 2 medium apples, peeled and cut into ¼-inch dice (about 2 cups)
- 50 g (¼ cup) brown sugar, 1 teaspoon cinnamon, 1 tablespoon flour, 1 tablespoon lemon juice, pinch of salt
- 1 egg beaten with 1 tablespoon water, and coarse sugar, for the tops

Method

1. Whisk the flour, sugar and salt. Cut in the cold butter until most is the size of small peas, with some larger flattened pieces.
2. Sprinkle on ice water a tablespoon at a time, tossing with a fork, until the dough holds together when squeezed. Press into a flat disk, wrap, and chill at least 1 hour.

3. Toss the filling ingredients together.
4. Heat the oven to 400 °F (200 °C). Roll the dough ⅛ inch thick and cut 4-inch circles; reroll scraps once.
5. Put a heaping tablespoon of filling on one half of each circle, brush the edge with water, fold over, and press closed with a fork. Cut a small steam vent in each.
6. Brush with egg wash, sprinkle with coarse sugar, and bake 20–25 minutes until deep golden.
7. Cool 15 minutes. Wash the bowls, pastry cutter and rolling pin.

Allergy check: Contains wheat, milk (butter) and eggs (egg wash). For egg-free, brush with milk or cream instead. For milk-free, use cold solid vegetable shortening or a plant-based butter stick in place of butter.

Steps

1. **Hypothesis.** Predict which crust will be flakier and which more tender, and why.
2. **Two half batches.** Make dough A with very cold butter (straight from the refrigerator, cubed and chilled 10 minutes more). Make dough B with butter left at room temperature for 1 hour (about 68 °F). Everything else identical. Record the butter temperature for each.
3. **Chill** both 1 hour, then roll each to ⅛ inch and make 5 hand pies from each, labeling the parchment.
4. **Bake** both trays the same way.
5. **Measure.** Cut a pie from each batch in half. Measure the crust's total thickness with a ruler and count the visible layers. Note color and greasiness.
6. **Taste panel.** Have family members rate flakiness and tenderness (1–5) without knowing which is which.
7. **Conclusion.** Explain the differences with gluten shortening, butter's water, and steam.
8. Clean up: scrape dough off counters with a bench scraper before wiping.

Tips

- If butter starts to melt and look shiny while you work, chill the bowl for 10 minutes.

- Flecks and streaks of butter in the rolled dough are good; they become the flakes.
- Cut the steam vent; otherwise the filling's steam bursts the seam.

Check your work

- ☐ I can explain how fat makes pastry tender and flaky.
- ☐ I can explain hydrogenation and why trans fats were removed from foods.
- ☐ I compared cold and soft fat in pastry and baked hand pies.

LAB NOTEBOOK

1. Draw a cross-section of pie dough before baking (flat butter sheets between dough) and after (layers lifted by steam).
2. Draw a fatty acid before and after hydrogenation, and a trans double bond compared with a cis one.
3. Record the comparison data and taste-panel results in a table.

KEY FORMULAS

$$\text{baker's } \% = \frac{m_{\text{ingredient}}}{m_{\text{flour}}} \times 100\%$$

$$V_{\text{steam}} \approx 1.7 \text{ L per gram of water at } 100\ ^\circ\text{C}$$

From history. Procter & Gamble promoted Crisco with cookbooks such as *The Story of Crisco* (1913), which offered hundreds of recipes. Normann's hydrogenation is also used to make margarine firmer; today most margarines use other methods to avoid trans fats.

WORKED EXAMPLES

Example 1. A crust uses 190 g flour, 140 g butter, 75 g ice water and 3 g salt. Write the baker's percentages.

Show solution

1. Flour 100%; butter $\frac{140}{190} \times 100\% = 74\%$; water 39%; salt 1.6%.

Answer: 100 : 74 : 39 : 1.6. Pie crusts are usually 60–80% fat and 30–40% water.

Example 2. The 140 g of butter is about 16% water. How much steam (in liters at 100 °C) can its water make?

Show solution

1. Water: $0.16 \times 140\ \text{g} = 22.4\ \text{g}$.
2. Steam: $22.4\ \text{g} \times 1.7\ \frac{\text{L}}{\text{g}} = 38\ \text{L}$.

Answer: About 38 liters of steam if it all vaporized at once, plus steam from the 75 g of added water. That expanding steam is what lifts the layers.

Example 3. Using the ideal gas law, check that 1 g of water makes about 1.7 L of steam at 100 °C (373 K) and 1 atm ($R = 0.0821\ \frac{\text{L·atm}}{\text{mol·K}}$).

Show solution

1. Moles: $\dfrac{1.00\ \text{g}}{18.02\ \text{g/mol}} = 0.0555\ \text{mol}$.
2. $V = \dfrac{nRT}{P} = \dfrac{(0.0555)(0.0821)(373)}{1.00}\ \text{L} = 1.70\ \text{L}$.

Answer: 1.70 L, about 1,700 times the volume of the liquid water.

Example 4. You need dough for 10 hand pies, using 30 g of dough per pie plus 10% for scraps. The recipe makes 408 g. Is one batch enough?

Show solution

1. Needed: $10 \times 30\ \text{g} \times 1.10 = 330\ \text{g}$.
2. 408 g > 330 g.

Answer: Yes; one batch is enough with about 78 g to spare.

PRACTICE

1. Easy In what year was Crisco introduced, and from what oil?

   Show answer

   1911, cottonseed oil.

2. **Easy** What does hydrogenation do to an unsaturated oil?

Show answer

Adds hydrogen to double bonds, making the fat more saturated and more solid.

3. **Easy** Why should pie dough be kept cold?

Show answer

So the fat stays solid in separate pieces that make flaky layers, rather than melting into the flour.

4. **Medium** Explain the two jobs fat does in pie crust.

Show answer

It coats flour so less gluten forms (tender), and flat cold pieces separate layers that steam lifts (flaky).

5. **Medium** Why were partially hydrogenated oils removed from U.S. foods?

Show answer

They contain trans fats, which research showed raise LDL cholesterol and heart-disease risk; the FDA determined in 2015 they were not generally recognized as safe.

6. **Medium** A crust uses 250 g flour and 180 g fat. Find the fat baker's percentage.

Show answer

72%

7. **Medium** Why does shortening make a crust that is easier to handle than butter?

Show answer

It stays solid over a wider range of temperatures and contains no water, so it does not soften and smear as quickly.

8. **Medium** How much steam (L at 100 °C) can 30 g of water make?

Show answer

$30 \times 1.7 = 51\ \text{L}$

9. Hard Scale the crust (190 g flour, 140 g butter, 75 g water, 3 g salt) for a double-crust 9-inch pie needing 650 g of dough.

Show answer

Batch mass 408 g; factor $650/408 = 1.59$: flour 303 g, butter 223 g, water 120 g, salt 5 g.

10. Hard A baker adds too much water and kneads the dough well. Predict the crust and explain.

Show answer

Tough and chewy, and it may shrink in the pan, because extra water and kneading develop gluten.

11. Challenge Why does lard make an especially flaky crust? Use what you know about crystal size and melting.

Show answer

Lard's fat crystals are large and it stays plastic (workable) over a wide temperature range, so it forms thin sheets that do not melt into the flour, and it contains almost no water to develop gluten.

COMMON MISTAKES

- Using soft butter or warm hands, so the fat melts into the flour.
- Adding all the water at once, making a sticky, tough dough.
- Overworking scraps by rerolling them many times.
- Skipping the chill, so the dough shrinks and the butter leaks in the oven.

> **Make it a game · Shortening Trap.** Tell your parent three statements about shortening: two true and one false. Include hydrogenation in 1902, Crisco in 1911, trans fat and why they were removed, and cold fat versus soft fat in pie crust. Your parent names the false one and fixes it. Swap and play five rounds.

5.5 Mège-Mouriès and Margarine

OBJECTIVES

- Tell how Hippolyte Mège-Mouriès answered Napoleon III's prize with oleomargarine in 1869.
- Compare butter, stick margarine and tub spreads by fat and water content, and explain why water content matters in baking.
- Measure the water in spreads by melting and separating them, and bake shortbread to test them.

> **Warm-up.** Look at the labels of a stick of butter and a tub of spread (or find them online). Compare the grams of fat per tablespoon. Why might two yellow spreads that look alike behave differently in a cookie?

WATCH

What Napoleon had to do with the Invention of Margarine

Today I Found Out · 6:33

https://www.youtube.com/watch?v=uAuz4CJdg_A

> **WHEN TO WATCH**
> During session 1, after the story. Listen for what Napoleon III wanted and what the first margarine was made of.

BACKUP VIDEO

Hippolyte Mège-Mouriès's Recipe for Margarine

Science History Institute · 0:49

https://www.youtube.com/watch?v=P3BrqMEJ9JE

A one-minute animation of Mège-Mouriès's original recipe: watch for each step from beef fat to finished spread.

KEY TERMS

margarine

A water-in-oil emulsion of fat (now usually vegetable oils) with water or milk, made to resemble butter; U.S. margarine must contain at least 80% fat.

oleo

The soft, low-melting part of beef fat that Mège-Mouriès separated and used; the source of the old name "oleomargarine."

spread

A product like margarine but with less than 80% fat (often 30–70%), so more water.

clarified butter

Butter melted and separated so that the water and milk solids can be removed, leaving nearly pure butterfat.

fractionation

Separating a fat into parts with different melting points by cooling and pressing.

CORE IDEAS

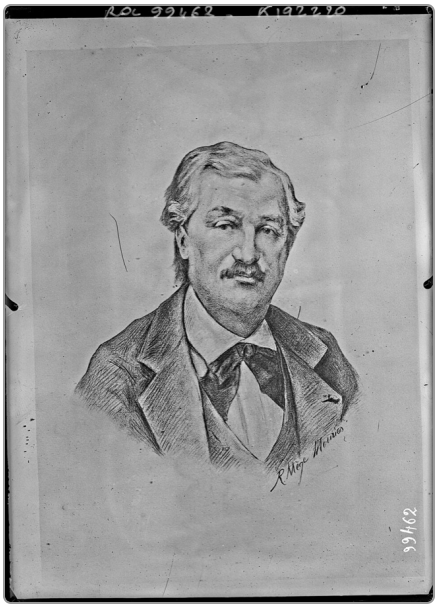
The story. In the 1860s butter was expensive in France, and the army, navy and working poor needed a cheaper fat that would keep. Emperor Napoleon III offered a prize for a butter substitute. The chemist Hippolyte Mège-Mouriès, who had already improved bread-making and other food processes, took up the challenge and in 1869 patented "oleomargarine." He won the prize, and factories in France, the Netherlands and America soon made it.

How they figured it out. Mège-Mouriès studied how cows make butterfat and guessed that the soft fraction of beef fat could be made to resemble butter. He gently warmed beef fat, let it cool, and pressed out the soft, low-melting part (the "oleo"), leaving the hard stearin behind. Then he churned the oleo with a little milk and water and chopped cow's udder (for its enzymes, he thought) to make an emulsion with the texture of butter. Over the next century margarine makers replaced beef fat with vegetable oils, hardened first by hydrogenation and now by blending. Butter makers fought hard against margarine; for decades some U.S. states taxed it or forbade coloring it yellow, so families bought white margarine with a capsule of yellow dye to knead in at home.

The kitchen science. Butter and margarine are both **water-in-oil emulsions.** By law in the United States, butter must be at least 80% milkfat, and stick margarine at least 80% fat; the rest is mostly water. Tub "spreads" have less fat (often 40–70%) and more water. In baking that difference is critical. A shortbread is mostly flour, sugar and fat with no added water; it depends on fat to coat the flour and keep gluten from forming. Swap in a spread with 40% water and the extra water develops gluten and dissolves sugar: the cookies spread, toughen or turn cakey. When butter is heated gently, its emulsion breaks: the water sinks and boils away, the milk solids sink or float as foam, and the clear yellow fat is **clarified butter**, which can be heated hotter without burning.

Let's cook. You will measure the water in butter and a spread, then bake shortbread with each. The skill is **creaming butter and sugar** and handling a crumbly dough gently.

PICTURE STUDY



Portrait of Hippolyte Mège-Mouriès, R. Mège-Mouriès, 19th century · Drawing · Bibliothèque nationale de France, Paris

Image: Wikimedia Commons, public domain

Hippolyte Mège-Mouriès (1817–1880) began as a pharmacist's assistant and became an inventive food chemist. This portrait is preserved in the national library of France and was apparently drawn by a member of his family.

Look closely

- Look at his face and expression. What kind of man does he seem to be?
- Look at his clothing. What does it tell you about the time he lived in?
- How does a drawing like this differ from a photograph of the same time?

Talk about it

1. Mège-Mouriès solved a problem for the poor and the navy. What qualities would a margarine need to keep on a long sea voyage?
2. Why do you think butter makers fought margarine so hard?
3. Margarine has been made from beef fat, hydrogenated oils and blended oils. What does this tell you about how food science changes over time?

Safety first. Melting butter for the water test: use low heat or short microwave bursts, because hot fat with water in it can spatter. Shortbread bakes at 325 °F; use mitts. Do not taste raw dough.

KITCHEN LAB

How Much Water Is in Your Spread?

You will melt butter and a spread in narrow glasses to measure their water layers, then bake two small batches of shortbread to see what the water does.

You will need

- Butter (stick) and a tub spread or soft margarine (check the fat on each label)
- Two narrow clear glasses (shot glasses or test tubes), a ruler and a marker
- A microwave or small saucepan
- A digital scale, two bowls, a mixer or wooden spoon
- Two 8-inch pans or a baking sheet
- Your lab notebook

Butter Shortbread

Serves 16 wedges or bars · Prep 15 min · Bake 30–40 min · Cool 20 min

Ingredients

- 226 g (1 cup, 2 sticks) butter, softened
- 100 g (½ cup) sugar
- 1 teaspoon vanilla extract
- 280 g (2¼ cups) all-purpose flour
- ½ teaspoon salt

Method

1. Heat the oven to 325 °F (165 °C).
2. Beat the butter and sugar until light and creamy, about 2 minutes. Beat in the vanilla.
3. Add the flour and salt and mix on low (or by hand) just until a crumbly dough forms that holds together when pressed. Do not taste the dough.
4. Press evenly into an 8- or 9-inch square or round pan. Prick all over with a fork and score into 16 pieces.

5. Bake 30–40 minutes, until pale golden at the edges and firm in the center.
6. Cut along the scored lines while warm; cool completely in the pan. Wash the bowl and beaters.

Allergy check: Contains milk (butter) and wheat. For milk-free, a plant-based butter stick that is about 80% fat works best; avoid tub spreads.

Steps

1. **Read labels.** Record the grams of fat per tablespoon (14 g) for each product and calculate the fat percentage.
2. **Melt test.** Melt 30 g of each product separately and pour into narrow glasses. Let them stand 15 minutes. Measure the height of the clear fat and of the cloudy water layer, and estimate each layer's volume (or weigh the poured-off fat).
3. **Calculate** the water percentage of each and compare with the label.
4. **Bake.** Make two half batches of shortbread, one with butter and one with the spread, identical otherwise. Bake side by side.
5. **Compare.** Measure spread (width) and thickness, and rate tenderness, crispness and flavor.
6. **Conclusion.** Explain the differences with water content, gluten and emulsions.
7. Clean up; save the clarified butterfat from the melt test for cooking.

Tips

- Use the fat on the label as a check: 11 g of fat per 14 g tablespoon means about 80% fat.
- Shortbread is done when it is pale gold, not brown; overbaking dulls the butter flavor.
- Clarified butter (the clear fat) keeps for weeks in the refrigerator and is good for high-heat cooking.

Check your work

☐ I can tell the history of margarine and Napoleon III's prize.

- ☐ I can explain why butter, margarine and spreads behave differently in baking.
- ☐ I measured the water in spreads and tested them in shortbread.

LAB NOTEBOOK

1. Draw butter, margarine and a spread as water-in-oil emulsions, showing their different amounts of water.
2. Record your melt-test data and calculations.
3. Make a timeline of margarine from 1869 to today.

KEY FORMULAS

$$\text{water } \% = \frac{V_{\text{water layer}} \times 1.00\ \text{g/mL}}{m_{\text{sample}}} \times 100\%$$

$$\text{fat } \% \approx 100\% - \text{water } \% - \text{solids } \%$$

From history. In the United States the Oleomargarine Act of 1886 put a tax on margarine, and many states banned yellow margarine for decades; the last state law, in Wisconsin, was repealed in 1967. During World War II, when butter was rationed, many families first tried margarine, kneading the yellow coloring into it at the kitchen table.

WORKED EXAMPLES

Example 1. You melt 100 g of butter in a narrow glass. After settling, the water and milk-solids layer at the bottom is 17 mL (take it as 17 g). Find the approximate water-plus-solids percentage and fat percentage.

Show solution

1. $\dfrac{17\ \text{g}}{100\ \text{g}} \times 100\% = 17\%$. Fat $\approx 83\%$.

Answer: About 17% water and milk solids, 83% fat, consistent with butter's legal minimum of 80% fat.

Example 2. A tub spread label says 7 g of fat per 14-g tablespoon. Find its fat percentage, and estimate how many grams of water a shortbread recipe would gain if 226 g of the spread replaced 226 g of butter (82% fat, 16% water). Assume the spread is about 48% water.

Show solution

1. Spread fat: $\dfrac{7}{14} \times 100\% = 50\%$.
2. Water from spread: $0.48 \times 226 = 108$ g; from butter $0.16 \times 226 = 36$ g.
3. Extra water: $108 - 36 = 72$ g.

Answer: About 72 g more water, roughly ⅓ cup, in a recipe that was designed to have almost none.

Example 3. Shortbread uses 226 g butter, 100 g sugar and 280 g flour. Write its baker's percentages and the fat-to-flour ratio.

Show solution

1. Flour 100%; butter $\dfrac{226}{280} \times 100\% = 81\%$; sugar 36%.
2. Butterfat: $0.82 \times 226 = 185$ g; fat : flour $= 185 : 280 \approx 0.66$.

Answer: 100 : 81 : 36, with about two-thirds as much fat as flour. That much fat is why shortbread is so tender ("short").

Example 4. To clarify 454 g (1 lb) of butter that is 82% fat, how much clarified butter will you get at most? If clarified butter costs \$14.00 per pound at the store and butter \$4.50, compare the cost per gram of fat.

Show solution

1. Clarified butter: $0.82 \times 454 = 372$ g.
2. Homemade: $\dfrac{\$4.50}{372\text{ g}} = \$0.0121$ per g; store: $\dfrac{\$14.00}{454\text{ g}} = \$0.0308$ per g.

Answer: About 372 g; homemade costs about 1.2¢ per gram versus about 3.1¢, about 40% of the store price.

PRACTICE

1. Easy Who invented margarine, and in what year?

Show answer

Hippolyte Mège-Mouriès, 1869.

2. Easy What is the minimum fat content of butter in the United States?

Show answer

80% milkfat.

3. Easy What kind of emulsion are butter and margarine?

Show answer

Water-in-oil.

4. Medium A spread has 5 g fat per 14 g tablespoon. Find its fat percentage.

Show answer

36%

5. Medium Why does a tub spread make shortbread spread and turn tough?

Show answer

Its extra water dissolves sugar and lets gluten develop, so the dough loosens and toughens.

6. Medium What did Mège-Mouriès separate from beef fat to make oleomargarine?

Show answer

The soft, low-melting fraction (oleo), by warming, cooling and pressing the fat.

7. Medium How is clarified butter made, and why can it be heated hotter than whole butter?

Show answer

Melt butter and remove the water and milk solids; the milk solids are what burn, so the pure fat has a higher smoke point.

8. Medium Find the fat in 300 g of butter at 81% fat.

Show answer

243 g

9. Hard A melt test of 40 g of spread leaves 22 mL of water layer. Estimate the water and fat percentages.

Show answer

Water about 55%; fat about 45%.

10. Hard A recipe calls for 113 g of butter (82% fat). How many grams of a 60%-fat spread give the same fat, and how much more water would that add (butter 16% water, spread 38%)?

Show answer

Fat 92.7 g; spread $92.7 / 0.60 = 155$ g; water
$0.38 \times 155 - 0.16 \times 113 = 59 - 18 = 41$ g more.

11. Challenge Margarine went from beef fat to hydrogenated vegetable oil to blended oils. Explain the reason for each change, and what that history shows about how food science works.

Show answer

Beef fat was the available solid fat; vegetable oils were cheaper and plentiful once hydrogenation could harden them; when research showed trans fats were harmful, makers changed methods. Food science improves as new evidence corrects old practice.

COMMON MISTAKES

- Substituting a tub spread for butter in cookies and pastry.
- Overmixing shortbread dough after the flour goes in.
- Heating whole butter too hot for frying; it burns. Use clarified butter or mix with oil.
- Assuming every yellow spread is the same.

> **Make it a game · Water in the Spread.** Set out butter, stick margarine and a tub spread. Without reading the labels, each of you guesses the percent fat and water in each. Compare with the nutrition panels and score one point per guess within five percent. Explain clarified butter. Tell how Mège-Mouriès answered the emperor's prize.

UNIT 5

Fats and Emulsions

Fats carry flavor, transfer heat, make pastry tender and flaky, and with the help of emulsifiers hold oil and water together in sauces and dressings. In this unit you will learn the chemistry of fats and oils from fatty acids to triglycerides, why some are solid and others liquid, how they behave in a hot pan, how emulsions form and break, and how fat and steam build a flaky crust.

The stories run from Chevreul's fatty acids and David Wesson's refined oil to Gobley's lecithin, Wilhelm Normann's hydrogenation and Crisco, and Mège-Mouriès's margarine. You will churn butter, measure oil temperature and absorption in shallow frying, time the separation of vinaigrettes, compare cold and soft fat in pastry, and measure the water in butter and spreads. The recipes are biscuits with homemade butter, crispy chicken cutlets, a chopped salad with honey-mustard vinaigrette, apple hand pies and shortbread.

PREREQUISITES

- Unit 2: polarity, hydrogen bonds, $q = mc\Delta T$
- Unit 4: gluten formation and baker's percentages
- Has used the stove and oven safely; a parent present for shallow frying

MASTERY CHECKLIST

- ☐ I can describe triglycerides and saturated, unsaturated and trans fatty acids, and relate structure to melting point.
- ☐ I can explain smoke point and oil temperature in frying, and fry safely without deep frying.
- ☐ I can explain emulsions and emulsifiers and make a stable vinaigrette.
- ☐ I can explain how fat makes pastry tender and flaky, and the history of hydrogenation and trans fats.
- ☐ I can compare butter, margarine and spreads and explain their behavior in baking.
- ☐ I can calculate yields, ratios, droplet surface area, steam volume and fat and water percentages.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FDA: Trans Fat**: Free. The FDA's explanation of trans fat and the removal of partially hydrogenated oils, for Lesson 5.4.
- **King Arthur Baking: Pie Crust Guide**: Free. Step-by-step photographs for mixing, rolling and crimping pie dough.
- **A clip-on frying thermometer**: Optional. Makes the shallow-frying lab in Lesson 5.2 easier and safer; an instant-read thermometer that reads to 400 °F also works.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

5.1	**Fatty Acids and Butter: Chevreul's Fats**	3 sessions of 50–90 minutes
5.2	**Smoke Points and Shallow Frying: David Wesson's Oil**	3 sessions of 50–90 minutes
5.3	**Emulsions and Emulsifiers: Gobley's Lecithin**	3 sessions of 50–90 minutes
5.4	**Shortening and Flakiness: Crisco and the Pie Crust**	3 sessions of 50–90 minutes
5.5	**Mège-Mouriès and Margarine**	3 sessions of 50–90 minutes

Unit 5 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   What did Chevreul show about fats in 1823, and how?

2. **6 pts**
   Explain why butter is solid at room temperature but olive oil is liquid.

3. **6 pts**
   Find the theoretical butter yield from 720 g of cream at 38% fat if butter is 81% fat. If you get 310 g, find the percent yield.

4. **5 pts**

   Linolenic acid is $C_{18}H_{30}O_2$. How many double bonds does it have? Explain.

5. **6 pts**

   Define smoke point and explain why refined oils have higher smoke points.

6. **7 pts**

   300 g of oil at 180 °C (c = 2.0 J/(g·°C)) receives 100 g of food at 10 °C (c = 3.0). Ignoring the burner, find the mixed temperature. Why is this an argument against crowding the pan?

7. **5 pts**

   Give two safety rules for shallow frying.

8. **6 pts**

   Explain how an emulsifier stabilizes an oil-in-water emulsion, and name two kitchen emulsifiers.

9. **6 pts**

   1 mL of oil is divided into droplets of radius 0.0010 cm. How many droplets, and what total surface area?

10. **5 pts**

    Make 300 mL of a 3 : 1 vinaigrette.

11. **7 pts**

    Explain both the tenderness and the flakiness of a good pie crust.

12. **6 pts**

    What is hydrogenation, and why were partially hydrogenated oils removed from U.S. foods?

13. **5 pts**

    How much steam at 100 °C can the water in 200 g of butter (16% water) make?

14. **6 pts**

    Why did Napoleon III offer a prize for a butter substitute, and what did Mège-Mouriès make it from?

15. **6 pts**

A spread has 8 g of fat per 14 g serving. Find its fat percentage and say whether it can be legally sold as margarine in the U.S.

16. **12 pts**

Short essay (5–7 sentences): Choose butter, a vinaigrette or mayonnaise. Explain what kind of emulsion it is, what keeps it together, what can make it break, and how a cook prevents or fixes that.

ANSWER KEY

1. That fats are compounds of glycerol and fatty acids; he split fats with alkali (as in soapmaking) and purified and characterized the fatty acids.
2. Butter is rich in saturated fatty acids with straight chains that pack tightly; olive oil is rich in cis-unsaturated fatty acids whose kinks keep them from packing.
3. $273.6/0.81 = 338$ g; $310/338 = 92\%$.
4. Three; it has 6 fewer hydrogens than stearic acid ($C_{18}H_{36}O_2$), and each double bond removes 2 H.
5. The temperature of continuous smoke as oil breaks down; refining removes free fatty acids and particles that break down at lower temperatures.
6. $600(180 - T) = 300(T - 10)$; $T = 123\ ^\circ\text{C}$. A large load drops the oil far below frying temperature, so food absorbs oil and gets soggy.
7. Any two: parent present; no more than ¼–½ inch of oil; lay food in away from you; lid and baking soda nearby; never water on a grease fire; turn off heat if oil smokes.
8. Its oil-loving tail enters the droplet and its water-loving head faces the water, coating droplets so they do not merge. Lecithin (egg yolk) and mustard.
9. One droplet 4.19×10^{-9} cm^3; 2.4×10^8 droplets; area each 1.26×10^{-5} cm^2, total 3.0×10^3 cm^2.
10. 225 mL oil, 75 mL vinegar.
11. Tender: fat coats flour, limiting gluten. Flaky: flat pieces of cold fat separate dough layers; in the oven the fat melts and its water and the dough's water turn to steam that lifts the layers apart.
12. Adding hydrogen to the double bonds of unsaturated oils with a catalyst to make them more solid. Partial hydrogenation makes trans fats, which raise heart-disease risk; the FDA removed them (determination 2015, by 2018).
13. $32\ \text{g} \times 1.7\ \text{L/g} = 54\ \text{L}$
14. Butter was costly and spoiled; the army, navy and poor needed a cheap fat that kept. He used the soft fraction (oleo) of beef fat, churned with milk and water.
15. 57%; no, margarine must be at least 80% fat, so it is a spread.
16. Answers vary. Full credit for correctly identifying the emulsion type (butter water-in-oil; vinaigrette and mayonnaise oil-in-water), naming the emulsifier or

structure, naming a cause of breaking (heat, too much oil too fast, temperature, too little emulsifier) and a correct remedy.

UNIT PROJECT: THE FAT LAB REPORT

Choose one question about fats in your family's cooking and answer it with a controlled experiment: for example, does butter, shortening or a blend make the flakiest pie crust; which oil makes the crispest shallow-fried potatoes at the same temperature; or which emulsifier makes the most stable homemade dressing over a week?

Run at least two trials of each treatment, measure something real (thickness and layers, oil absorbed, separation height, a blind taste-panel score), and write a full lab report with a graph. Include a one-paragraph explanation of the fat chemistry involved and a note on safety. Serve the winning version to your family.

LOOK FOR	WHAT IT MEANS
Safety	Hot oil handled only with a parent present, no deep frying, fire safety ready; cleanup complete.
Experimental design	One variable, controls named, at least two trials each, a real measurement.
Data and graph	Clear table with units; appropriate graph with labeled axes.
Fat chemistry	Correct explanation using fatty acids, melting, smoke point, emulsions or steam.
Conclusion	Answers the question honestly from the data, with sources of error and an improvement.

UNIT 6

Microbes I: Fermentation

Some of the oldest and best foods are made by microbes: bread, yogurt, cheese, sauerkraut, pickles and vinegar. In this unit you will learn how yeasts and bacteria change food by fermentation, how their products raise bread, sour vegetables and preserve food, and how cooks keep the good microbes working and the harmful ones out.

The stories follow Louis Pasteur proving that fermentation is alive, the Fleischmann brothers bringing reliable yeast to American kitchens, the gold-rush "sourdoughs" and the USDA scientists who named their bacterium, Captain Cook's sauerkraut, and Ruth at Boaz's table. You will measure yeast activity, oven spring, a starter's pH, sauerkraut's pH over three weeks and the acid in vinegar, and you will bake a honey whole-wheat loaf and a no-knead crusty loaf, cook sourdough pancakes, ferment sauerkraut and make a sweet-and-sour stir-fry.

PREREQUISITES

- Unit 3: sugars and starch
- Unit 4: gluten and baker's percentages
- Comfort with logarithms for pH (taught as needed) and with moles and molar mass (taught in Lessons 2.1 and 4.1)

MASTERY CHECKLIST

- ☐ I can explain how Pasteur showed fermentation is caused by living microbes.
- ☐ I can use the yeast fermentation equation and molar volume to calculate CO_2 produced.
- ☐ I can explain oven spring with the gas laws, steam and the setting of starch and gluten.
- ☐ I can explain how wild yeasts and lactic acid bacteria make sourdough and sauerkraut, and why pH 4.6 matters.
- ☐ I can calculate salt percentages and pH ratios, and measure acid in vinegar by neutralization.
- ☐ I baked two breads and made a starter, sauerkraut and a sweet-and-sour dish safely.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **National Center for Home Food Preservation: Fermenting**: Free. Tested methods for sauerkraut and fermented pickles from the University of Georgia; see the "Ferment" section for Lesson 6.4.
- **King Arthur Baking: Sourdough Guides**: Free. Feeding schedules, troubleshooting and recipes for Lesson 6.3.
- **pH test strips**: Used in Lessons 6.3–6.5. Inexpensive strips covering about pH 2–9 are enough.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

6.1 Pasteur Proves Fermentation Is Alive — 3 sessions of 50–90 minutes (plus rising time)

6.2 Yeast Biology and Oven Spring: The Fleischmann Brothers
3 sessions of 50–90 minutes (plus 12–18 hours of rising)

6.3 Sourdough: Wild Yeast, Lactic Acid Bacteria and the Gold Rush
3 sessions of 50–90 minutes (plus a week of feeding)

6.4 Lactic Fermentation: Captain Cook's Sauerkraut
3 sessions of 50–90 minutes (plus 3–4 weeks of fermenting)

6.5 Vinegar and Acetic Acid: Dip Thy Morsel — 3 sessions of 50–90 minutes

Unit 6 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **8 pts**
   Describe what Pasteur saw in the Lille vats and what he concluded about fermentation.

2. **7 pts**

   Write the overall equation for what yeast does to glucose in dough, and find the CO_2 volume at 25 °C from 27.0 g of glucose.

3. **5 pts**

   What happens to yeast at 40 °F, 90 °F and 140 °F?

4. **6 pts**

   Gas in dough at 24 °C is heated to 100 °C. Find the expansion factor and explain why real oven spring is often greater.

5. **5 pts**

   A loaf rises from 6.0 cm to 9.9 cm in the oven. Find the oven spring.

6. **6 pts**

   Write the baker's percentages for 500 g flour, 400 g water, 10 g salt and 2 g yeast.

7. **6 pts**

   Explain why the yeast and bacterium of San Francisco sourdough coexist.

8. **6 pts**

   A starter's pH drops from 5.8 to 3.8. By what factor did $[H^+]$ change?

9. **6 pts**

   How much salt for 1,600 g of cabbage at 2.25%?

10. **7 pts**

    Explain the roles of salt, lack of air, and lactic acid bacteria in making sauerkraut safe.

11. **5 pts**

    How did Captain Cook persuade his sailors to eat sauerkraut?

12. **7 pts**

    100.0 g of vinegar with excess baking soda loses 3.5 g of CO_2. Find the acetic acid percentage.

13. **5 pts**

    Why must vinegar for tested pickling recipes be at least 5% acidity?

14. **6 pts**

    Name three signs that a ferment must be discarded.

15. **15 pts**

    Short essay (6–8 sentences): Compare yeast bread, sourdough and sauerkraut as fermented foods. For each, name the microbes, the main products and what those products do to the food, and explain one thing the cook does to help the right microbes win.

ANSWER KEY

1. Yeast cells in good vats and rod-shaped microbes in spoiled ones; fermentation is caused by living microorganisms, each kind of fermentation by its own microbe.
2. $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$. $27.0/180.2 = 0.150$ mol; CO_2 $0.300 \times 24.5 = 7.35$ L.
3. Very slow; works well; killed.
4. $373/297 = 1.26$. CO_2 also comes out of solution, yeast works until it dies, and water turns to vapor.
5. 65%.
6. 100, 80, 2, 0.4.
7. The bacterium uses maltose, which that yeast does not, so they do not compete; the bacteria's acid keeps out other microbes.
8. 100 times.
9. 36 g.
10. Salt draws out water to make brine and slows spoilage bacteria; keeping cabbage submerged excludes air, stopping molds and favoring lactic acid bacteria; the bacteria make lactic acid, dropping the pH below 4.6 so botulism and most pathogens cannot grow.
11. He had it served to the officers every day; seeing the officers enjoy it, the crew wanted it too.
12. $3.5 \times 60.05/44.01 = 4.8$ g; 4.8%.
13. To ensure the pickled food reaches a safely low pH.
14. Pink, orange or black color; fuzzy mold; rotten (not sour) smell; slimy texture.
15. Answers vary. Full credit for: bread, baker's yeast, CO_2 (rise) and a little ethanol (flavor, baked off), cook controls temperature and time; sourdough, wild yeasts plus lactic acid bacteria, CO_2 plus lactic and acetic acids (rise, flavor, keeping), cook feeds regularly; sauerkraut, lactic acid bacteria, lactic acid (sourness, preservation below pH 4.6), cook weighs salt and keeps cabbage under brine.

UNIT PROJECT: THE FERMENTATION LOG

Keep a four-week fermentation log for two ferments running at the same time: your sourdough starter (or a batch of yogurt or a second sauerkraut) and your sauerkraut. Record date, temperature, pH, appearance, smell, and every feeding or check, with photographs or sketches, and graph pH over time for both on the same axes.

Finish with a two-page report comparing the two ferments: the microbes involved, the products they make, why each became safe, what you would change, and one family meal that used your fermented foods, with a word of thanks.

LOOK FOR	WHAT IT MEANS
Safety and cleanliness	Clean tools, correct salt by weight, ferments kept submerged or fed, spoiled batches discarded.
Complete log	Regular, honest entries with dates, temperatures and pH.
Graph	Both pH curves on one labeled graph with the 4.6 line marked.
Science explanation	Correct use of fermentation, lactic acid bacteria, yeast, pH and succession.
Reflection	Thoughtful comparison, improvements and the family meal.

6.1 Pasteur Proves Fermentation Is Alive

OBJECTIVES

- Tell how Louis Pasteur showed between 1857 and 1860 that fermentation is the work of living microorganisms.
- Write and use the equation for what yeast does to sugar in bread dough, and calculate the carbon dioxide produced.
- Measure yeast activity at three temperatures, and bake a honey whole-wheat sandwich loaf.

> **Warm-up.** Stir ½ teaspoon of yeast and 1 teaspoon of sugar into ¼ cup of warm water in a clear glass. Watch it for the whole warm-up. What do you see on the surface after 5 minutes? After 10? Is something alive in the glass?

WATCH

How Does Bread Rise?

BrainStuff - HowStuffWorks · 2:08

https://www.youtube.com/watch?v=GvD-8ZfxfOY

> **WHEN TO WATCH**
> During session 1. Listen for the two jobs yeast does in dough and the role of gluten in holding the gas.

BACKUP VIDEO

Yeast and Sugar Experiment using Balloons (Fermentation)

The Food Tech Teacher · 3:00

https://www.youtube.com/watch?v=uNy2-PHkFH8

Before the lab. A food-technology teacher runs the same balloon test you will, with different amounts of sugar.

KEY TERMS

fermentation

Energy-releasing chemistry carried out by microorganisms without oxygen, turning sugars into acids, gases or other products.

yeast

A single-celled fungus. Baker's yeast is *Saccharomyces cerevisiae*.

spontaneous generation

The old belief that living things such as microbes arise from nonliving matter. Pasteur's experiments disproved it.

enzyme

A protein that speeds up a specific chemical reaction in living things; yeast's enzymes break sugars down.

molar volume

The volume of one mole of a gas: about 24.5 L at 25 °C and 1 atm.

CORE IDEAS

The story. In 1856 Louis Pasteur was dean of the new science faculty at Lille, a French industrial city. A local factory owner who fermented beet juice asked him for help: some of his vats were going sour and spoiling. Pasteur took samples to his microscope. In good vats he saw round, budding yeast cells; in spoiled vats he saw tiny rod-shaped organisms instead. In 1857 he published a famous paper on lactic fermentation (the souring of milk), and in 1860 one on yeast.

How they figured it out. Many leading chemists, including the great Justus von Liebig, held that fermentation was a purely chemical breakdown, and that yeast was a byproduct or a dying substance. Pasteur showed that fermentation happens only when living cells are present and multiplying, that each kind of fermentation has its own kind of microbe, and that killing the microbes with heat stops it. His swan-neck flask experiments (1859–1862) then showed that broth boiled and protected from airborne dust stays unspoiled, defeating the idea of spontaneous generation. Pasteur became convinced that "fermentation is life without air." (In 1897 Eduard Buchner showed that juice pressed from yeast could ferment sugar even without living cells, proving that the work is done by enzymes the cells make.)

The kitchen science. Baker's yeast feeds on sugars in dough: some added, and many released from starch by flour's own enzymes. Without much oxygen, yeast breaks

glucose down by the overall reaction $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$. The carbon dioxide inflates thousands of tiny bubbles held in the gluten network, and the dough rises. The small amount of ethanol formed in dough is a flavor-maker and evaporates during baking, along with much of the water near the crust. Yeast is alive, so temperature matters: it is sluggish below about 50 °F (10 °C), works best around 75–95 °F (24–35 °C), slows above about 110 °F (43 °C) and is killed at about 140 °F (60 °C). Salt slows yeast, and sugar feeds it, but too much sugar pulls water out of the cells and slows it again.

Let's cook. You will bake a honey whole-wheat sandwich loaf and keep a rise log. The skill is **reading the dough**: knowing when it has doubled by the poke test (a floured fingertip leaves a dent that springs back slowly).

PICTURE STUDY



Louis Pasteur, Albert Edelfelt, 1885 · Oil on canvas · Musée d'Orsay, Paris

Image: Wikimedia Commons, public domain

The Finnish painter Albert Edelfelt painted Pasteur in his laboratory in Paris at the height of his fame. Pasteur was a devout man who saw his science as a way of understanding and serving God's creation.

Look closely

- Find the jar Pasteur is holding. Why might he hold it up to the light?
- Look at the table. What objects tell you this is a laboratory?
- Look at his face. What does Edelfelt want you to think about him?
- Find the notebook. Why would a scientist keep careful notes?

Talk about it

1. Pasteur showed that fermentation needs living microbes. How does your rising dough prove the same thing?
2. Pasteur's opponents were famous scientists. How did experiments, rather than reputation, settle the argument?
3. How did Pasteur's discoveries change the way we keep milk, juice and many other foods safe?

> **Safety first.** Never taste raw dough. Use water no hotter than about 110 °F (43 °C) for the yeast (hotter water is uncomfortable to touch and kills yeast near 140 °F). Bake the loaf at 350 °F with mitts and let it cool on a rack.

KITCHEN LAB

Yeast at Three Temperatures

How does temperature change the rate of fermentation? You will put identical yeast mixtures under balloons at three temperatures and measure the gas produced, then bake a loaf and keep a rise log.

You will need

- Three identical clean bottles (about 16–20 oz) and three identical balloons
- Instant or active dry yeast and sugar
- A thermometer, a measuring cup and a funnel
- Three bowls for water baths (ice water, warm water, hot water) and a string and ruler
- A 9 × 5-inch loaf pan
- Your lab notebook

Honey Whole-Wheat Sandwich Loaf

Serves 1 loaf (14–16 slices) · Prep 20 min · Rise 1½–2½ hr · Bake 35–40 min

Ingredients

- 250 g (2 cups) whole-wheat flour
- 200 g (1⅔ cups) bread flour
- 7 g (2¼ teaspoons, 1 packet) instant yeast
- 9 g (1½ teaspoons) salt
- 320 g (1⅓ cups) warm water, about 100 °F (38 °C)
- 40 g (2 tablespoons) honey
- 28 g (2 tablespoons) soft butter or vegetable oil

Method

1. Stir the flours, yeast and salt in a large bowl. Add the water, honey and butter and mix into a shaggy dough.
2. Knead 8–10 minutes on a lightly floured counter until smooth and springy. Whole-wheat dough stays slightly tacky. Do not taste the dough.

3. Place in an oiled bowl, cover, and mark the starting height with tape. Let rise until doubled, 1–1½ hours.
4. Press out the gas, shape into a log, and place seam-side down in a greased loaf pan. Cover and let rise until it crowns about 1 inch above the rim, 45–60 minutes.
5. Bake at 350 °F (175 °C) for 35–40 minutes, until browned and the center reads 190–200 °F (88–93 °C).
6. Turn out onto a rack and cool at least 1 hour before slicing. Wash bowls in cool water first, then hot soapy water.

Allergy check: Contains wheat and milk (butter). For milk-free, use oil. Honey is never given to babies under one year.

Steps

1. **Hypothesis.** Rank the three temperatures by how fast you expect gas to form, and say why.
2. **Prepare.** In each bottle put 1 packet (7 g) yeast, 2 tablespoons sugar and 1 cup of water at about 100 °F. Swirl, stretch a balloon over each neck.
3. **Water baths.** Stand one bottle in ice water (about 40 °F), one in warm water (about 95 °F) and one in hot water (about 140 °F). Record each bath's temperature every 10 minutes and adjust with ice or hot water.
4. **Measure.** Every 10 minutes for 40 minutes, measure each balloon's circumference with string and a ruler.
5. **Calculate** the gas volume for each balloon with the sphere formula and graph volume against time.
6. **Bake** the loaf. Keep a rise log: dough height every 15 minutes, room temperature, the poke test, oven spring and center temperature.
7. **Conclusion.** Explain the balloon results with yeast as a living organism, and estimate the mass of sugar fermented in the warm bottle.
8. Clean up: pour the yeast mixtures down the drain with plenty of water; wash bottles.

Tips

- Instant yeast can go straight into the flour; active dry yeast is often dissolved in warm water first.

- In a cool kitchen, let dough rise in the oven with only the light on.
- The thumping sound of a hollow loaf bottom is a rough test; the thermometer is better.

Check your work

- ☐ I can tell how Pasteur showed fermentation is alive.
- ☐ I can use the fermentation equation to calculate the CO_2 from sugar.
- ☐ I measured yeast activity at three temperatures and baked a loaf with a rise log.

LAB NOTEBOOK

1. Draw a yeast cell budding, and a molecule-level sketch of glucose becoming ethanol and carbon dioxide.
2. Graph balloon gas volume against time for the three temperatures.
3. Record the rise log and the loaf's final height, crumb and family rating.

KEY FORMULAS

$$\mathrm{C_6H_{12}O_6} \rightarrow 2\,\mathrm{C_2H_5OH} + 2\,\mathrm{CO_2}$$

$$V_{\text{gas}} = n \times 24.5\ \text{L/mol}\ \ (25\ ^\circ\text{C},\ 1\ \text{atm})$$

$$V_{\text{sphere}} = \frac{C^3}{6\pi^2}\ \ (C = \text{circumference})$$

From history. Pasteur's work on fermentation led him to study diseases of silkworms, then of animals and people; he developed vaccines for chicken cholera, anthrax and rabies. The Pasteur Institute he founded in Paris in 1887 is still a leading center of microbiology.

WORKED EXAMPLES

Example 1. Yeast ferments 10.0 g of glucose (180.2 g/mol). How many moles and liters of CO_2 form at 25 °C?

Show solution

1. Moles glucose: $\dfrac{10.0}{180.2} = 0.0555$ mol.
2. CO_2: $2 \times 0.0555 = 0.111$ mol.
3. Volume: $0.111 \times 24.5\ \text{L/mol} = 2.72$ L.

Answer: About 2.7 L of CO_2 from just 10 g of sugar.

Example 2. A balloon on a yeast bottle has a circumference of 30 cm. Estimate the gas inside.

Show solution

1. $V = \dfrac{C^3}{6\pi^2} = \dfrac{30^3}{6(9.87)}\ \text{cm}^3 = \dfrac{27{,}000}{59.2}\ \text{cm}^3 = 456\ \text{cm}^3$.

Answer: About 460 mL of gas (treating the balloon as a sphere).

Example 3. A loaf's dough contains 7 g of yeast and makes about 1.5 L of gas during its rises. About what mass of glucose did the yeast ferment?

Show solution

1. Moles CO_2: $\dfrac{1.5\ \text{L}}{24.5\ \text{L/mol}} = 0.061$ mol.
2. Glucose: $\dfrac{0.061}{2} = 0.031$ mol; $0.031 \times 180.2 = 5.5$ g.

Answer: About 5.5 g of sugar, a small fraction of the loaf. (Much gas also escapes or dissolves, so the true amount is somewhat higher.)

Example 4. Write the baker's percentages for 250 g whole-wheat flour, 200 g bread flour, 320 g water, 40 g honey, 28 g butter, 9 g salt and 7 g yeast.

Show solution

1. Total flour: $450\ \text{g} = 100\%$.
2. Water $\dfrac{320}{450} = 71\%$; honey 8.9%; butter 6.2%; salt 2.0%; yeast 1.6%.

Answer: Flour 100 (whole wheat 56, bread 44), water 71, honey 8.9, butter 6.2, salt 2.0, yeast 1.6. Whole wheat absorbs more water, so the hydration is higher than for white bread.

PRACTICE

1. Easy What did Pasteur see in the good vats and in the spoiled vats at Lille?

   Show answer

   Budding yeast cells in the good vats; tiny rod-shaped microbes in the spoiled ones.

2. Easy What gas makes bread dough rise?

   Show answer

   Carbon dioxide.

3. Easy At about what temperature is yeast killed?

   Show answer

   About 140 °F (60 °C).

4. Medium How many moles of CO_2 come from 0.50 mol of glucose?

   Show answer

   1.0 mol.

5. Medium Find the volume of CO_2 at 25 °C from 18.0 g of glucose.

   Show answer

   $0.0999 \times 2 \times 24.5 = 4.9\ \text{L}$

6. Medium A balloon's circumference is 24 cm. Estimate its volume.

   Show answer

   $24^3/59.2 = 234\ \text{cm}^3$

7. Medium Why does salt slow a rise, and why do bakers still use it?

Show answer

Salt draws water from yeast cells and slows fermentation; it also strengthens gluten and greatly improves flavor.

8. Medium What did Buchner show in 1897, and how did it refine Pasteur's view?

Show answer

Juice from ground yeast, with no living cells, could still ferment sugar; the work is done by enzymes the living cells make.

9. Hard Dough rises from 600 mL to 1,250 mL. What volume of gas was added, and roughly what mass of glucose was fermented (24.5 L/mol)?

Show answer

650 mL; $0.65 / 24.5 = 0.0265$ mol CO_2; glucose $0.0133 \times 180 = 2.4$ g.

10. Hard A recipe written for 7 g of yeast rises in 1 hour at 80 °F. Why might it take 2 hours in a 65 °F kitchen, and what could you do?

Show answer

Yeast works more slowly at lower temperature; let it rise longer, or find a warmer spot (an oven with only the light on).

11. Challenge Using molar masses, show that the fermentation equation conserves mass (C 12.01, H 1.008, O 16.00).

Show answer

Glucose 180.16; ethanol 46.07 × 2 = 92.14; CO_2 44.01 × 2 = 88.02; total 180.16. Mass is conserved.

COMMON MISTAKES

- Using water that is too hot and killing the yeast.
- Adding salt directly onto the yeast in a small bowl of water.
- Judging a rise by the clock instead of by the dough.
- Slicing hot bread, which makes the crumb gummy.

Make it a game · Sugar to Gas. Write the balanced equation for yeast fermenting glucose from memory. Your parent gives a mass of sugar, such as 180 grams. Calculate the moles and the liters of carbon dioxide at 22.4 liters per mole. Do four calls and time yourself. Tell how Pasteur proved fermentation is alive between 1857 and 1860.

6.2 Yeast Biology and Oven Spring: The Fleischmann Brothers

OBJECTIVES

- Tell how Charles and Max Fleischmann made reliable compressed yeast in Cincinnati from 1868 and introduced it at the 1876 Centennial Exhibition.
- Explain oven spring with the gas laws, the boiling of water and the setting of starch and gluten.
- Bake a no-knead Dutch-oven loaf and measure its oven spring.

> **Warm-up.** Look at a slice of bakery bread and a slice of sandwich bread through a magnifying glass. Measure a few of the largest holes. What made them? Why would one bread have bigger holes than the other?

WATCH

The physics of baking

Harvard Online · 4:23

https://www.youtube.com/watch?v=dXCrTJLk_kY

> **WHEN TO WATCH**
> During session 1. Note what happens to gas, water and starch at each stage of baking.

BACKUP VIDEO

How Does Bread Rise?

BrainStuff - HowStuffWorks · 2:08

https://www.youtube.com/watch?v=GvD-8ZfxfOY

If you did not watch it in Lesson 6.1, watch it now for the basics of yeast and gluten.

KEY TERMS

compressed yeast
Fresh yeast cells pressed into moist cakes; reliable and uniform. Dry and instant yeasts came later (1940s and 1970s).

oven spring
The rapid rise of a loaf in the first 10–15 minutes of baking.

Charles's law

At constant pressure, a gas's volume is proportional to its absolute temperature: $V_1/T_1 = V_2/T_2$.

crumb

The inside of a loaf, with its pattern of holes (cells).

hydration

Water as a percentage of flour mass; wetter doughs make larger, more open holes.

CORE IDEAS

The story. In the mid-1800s most American home bakers made their own leaven from potatoes, hops or leftover dough, and results varied from batch to batch. Charles Fleischmann, a Hungarian-born yeast maker, came to the United States, found American bread disappointing, and with his brother Max and the businessman James Gaff began producing a standardized compressed yeast in Cincinnati in 1868. At the Centennial Exhibition in Philadelphia in 1876 they built a model Viennese bakery and sold fresh bread and their yeast to the crowds. Reliable yeast changed home baking across the country.

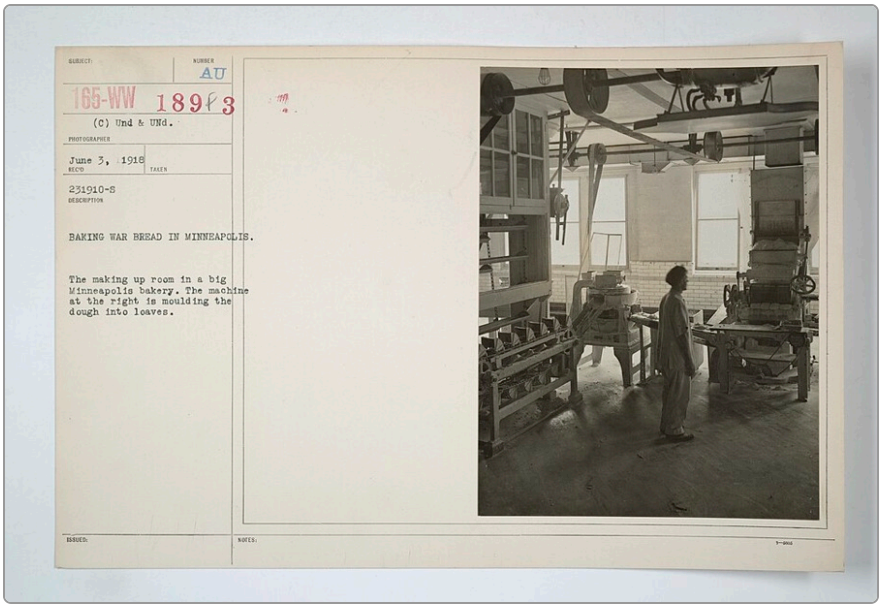
How they figured it out. The key was to grow a single, vigorous strain under controlled conditions, then wash, press and deliver it fresh, keeping it cool so it stayed alive. Later, food scientists dried yeast into granules (active dry yeast, developed during World War II for soldiers far from bakeries) and finally into fast-acting instant yeast. Each step made the living ingredient easier to store and more predictable.

The kitchen science. A rising loaf is a foam of gas cells held by gluten. In the oven, the loaf rises again quickly, its **oven spring**, for several reasons at once. Heat makes the gas already in the cells expand (Charles's law: volume grows with absolute temperature). Carbon dioxide dissolved in the dough's water comes out of solution as the dough warms. Yeast works furiously until about 140 °F (60 °C), when it dies. And water in the dough begins to turn to vapor, swelling the cells further. Meanwhile, starch gelatinizes and gluten proteins set between about 150 and 180 °F (65–82 °C), and the crust dries and browns; once the outside sets, the rise stops. Baking in a covered pot traps steam around the loaf, keeping the crust soft and stretchy longer

so the loaf can rise more before it sets; removing the lid lets the crust dry, crisp and brown. A long, cool rise with very little yeast gives enzymes time to develop flavor.

Let's cook. You will bake a no-knead crusty loaf: a wet dough left 12–18 hours, during which time does the work of kneading, then baked in a very hot covered Dutch oven. The skill is **handling the hot pot** safely, with a parent present.

PICTURE STUDY



Baking War Bread in Minneapolis, U.S. government photographer, c. 1918 · Photograph · National Archives, College Park, Maryland

Image: Wikimedia Commons, public domain

During World War I the United States asked bakers to make “war bread” that used less wheat so more could be shipped to the Allies. This photograph shows the making-up room of a big Minneapolis bakery, where dough was divided, shaped and panned.

Look closely

- Find the machine at the right. What job is it doing?
- Read the typed card beside the photograph. What does it tell you about when and why the picture was taken?
- Look at the workers’ white clothes and caps. Why would a bakery require them?
- Find the troughs or tables of dough. How would the bakers keep it rising at the right speed?

Talk about it

1. Reliable commercial yeast made bakeries like this possible. What would happen to a bakery if every batch of yeast behaved differently?
2. Why did the government ask bakers to save wheat during the war, and what might they use instead?

3. How is baking for thousands different from baking one loaf for your family? What is the same?

Safety first. The Dutch oven is heated empty to 450 °F: work with a parent present, use long, thick oven mitts on both hands, set the lid upside down on a heat-proof surface, and lower the dough in on parchment so your hands never go near the pot. Never taste raw dough.

KITCHEN LAB

Measuring Oven Spring

How much does a loaf rise in the oven, and when? You will measure the height of a no-knead loaf before and after baking, check its height when the lid comes off, and compare the result with Charles's law.

You will need

- A 5–7 quart Dutch oven or heavy lidded pot that can go in a 450 °F oven
- Parchment paper, a large bowl and plastic wrap
- A ruler, an instant-read thermometer and a timer
- Long, thick oven mitts
- Your lab notebook

No-Knead Crusty Bread

Serves 1 round loaf (10–12 slices) · Mix 5 min · Rise 12–18 hr plus 1–2 hr · Bake 45 min

Ingredients

- 400 g (3¼ cups) bread flour or all-purpose flour
- 8 g (1¼ teaspoons) salt
- 1 g (¼ teaspoon) instant yeast
- 345 g (1½ cups) cool water

Method

1. Stir the flour, salt and yeast in a large bowl. Add the water and stir until no dry flour remains; the dough will be wet and shaggy. Do not taste it.
2. Cover and leave at room temperature (about 68–72 °F) for 12–18 hours, until bubbly and more than doubled.
3. Scrape the dough onto a floured counter, fold it over itself a few times into a rough ball, and set it seam-side down on a sheet of parchment. Cover with a towel and let rise 1–2 hours.
4. Half an hour before baking, put the empty covered Dutch oven in the oven and heat to 450 °F (230 °C).

5. With a parent present and long mitts on, take out the pot, remove the lid, and lower the dough in by the parchment. Cover and bake 30 minutes.
6. Remove the lid and bake 10–15 minutes more, until deep brown and the center reads about 205–210 °F (96–99 °C).
7. Lift out by the parchment and cool on a rack at least 1 hour. Let the pot cool completely before washing it.

Allergy check: Contains wheat.

Steps

1. **Predict** the oven spring using Charles's law (dough at room temperature heated to 100 °C), and decide whether the real spring will be larger or smaller, and why.
2. **Measure before.** Just before baking, measure the dough's height and width on the parchment.
3. **Measure at 30 minutes.** When you remove the lid, quickly measure the loaf's height with a ruler held beside the pot (do not touch the pot). Note the crust's color.
4. **Measure after.** Measure the finished height and width, and the center temperature.
5. **Calculate** oven spring at 30 minutes and at the end. How much of the rise happened under the lid?
6. **Crumb.** When cool, slice the loaf in half, trace or photograph the crumb, and measure the five largest holes.
7. **Conclusion.** Explain your oven spring with the gas laws, steam, yeast and the setting of starch and gluten.
8. Clean up when the pot is cool.

Tips

- A long, cool rise makes better flavor; if your kitchen is warm, 12 hours may be plenty.
- If the dough spreads flat, it may have over-risen; next time shorten the second rise.

- No Dutch oven? Bake on a hot baking sheet with a large metal bowl turned over the loaf for the first 30 minutes.

Check your work

- ☐ I can tell how reliable commercial yeast changed baking.
- ☐ I can explain oven spring with Charles's law, steam, yeast and setting.
- ☐ I baked a no-knead loaf safely and measured its oven spring.

LAB NOTEBOOK

1. Draw a timeline of a loaf in the oven from 75 °F to 210 °F, marking gas expansion, yeast death, starch gelatinization, protein setting and browning.
2. Record your height measurements and oven-spring calculations.
3. Trace the crumb and label the largest cells.

KEY FORMULAS

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad (T \text{ in kelvins: } K = {}^\circ\mathrm{C} + 273)$$

$$\text{oven spring } \% = \frac{h_{\text{baked}} - h_{\text{before}}}{h_{\text{before}}} \times 100\%$$

From history. Active dry yeast was developed during World War II so armies could bake bread without refrigerated fresh yeast. Instant yeast, with smaller particles that need no dissolving, was introduced in the 1970s. Today a single commercial yeast plant can produce many tons of yeast a day.

WORKED EXAMPLES

Example 1. Gas cells in dough at 27 °C are heated to 100 °C. By what factor does the gas expand from heating alone (at constant pressure)?

Show solution

1. $T_1 = 27 + 273 = 300$ K; $T_2 = 100 + 273 = 373$ K.
2. $\dfrac{V_2}{V_1} = \dfrac{373}{300} = 1.24.$

Answer: About 24% larger. Real oven spring is often larger because of CO_2 leaving solution, final yeast activity and water vapor.

Example 2. A loaf is 6.5 cm tall when it goes into the oven and 10.4 cm tall when it comes out. Find the oven spring.

Show solution

1. $\dfrac{10.4 - 6.5}{6.5} \times 100\% = 60\%$.

Answer: 60% oven spring.

Example 3. The no-knead loaf uses 400 g flour, 345 g water, 8 g salt and 1 g instant yeast. Find the hydration and yeast percentages, and compare the yeast with the 1.6% in Lesson 6.1's loaf.

Show solution

1. Hydration: $\dfrac{345}{400} = 86\%$. Salt: 2.0%. Yeast: $\dfrac{1}{400} = 0.25\%$.
2. $\dfrac{1.6\%}{0.25\%} = 6.4$.

Answer: 86% hydration and 0.25% yeast, about one-sixth as much yeast as the sandwich loaf, which is why it needs 12–18 hours.

Example 4. If yeast doubles its gas output for every 10 °C rise (in its working range), how much longer will a dough take to rise at 18 °C than at 28 °C?

Show solution

1. $2^{10/10} = 2$.

Answer: About twice as long. Bakers use cool, slow rises on purpose to develop flavor.

PRACTICE

1. Easy In what year did the Fleischmanns begin making compressed yeast in Cincinnati?

   Show answer

   1868.

2. Easy What is oven spring?

Show answer

The quick rise of a loaf in the first part of baking.

3. Easy Convert 25 °C to kelvins.

Show answer

298 K.

4. Medium Gas at 20 °C is heated to 95 °C. By what factor does its volume increase?

Show answer

$368/293 = 1.26$

5. Medium A loaf goes from 7.0 cm to 11.2 cm. Find the oven spring.

Show answer

60%.

6. Medium Why does baking with a lid on at first give a taller loaf?

Show answer

Trapped steam keeps the crust moist and stretchy longer, so the loaf can keep expanding before the crust sets.

7. Medium Name four causes of oven spring.

Show answer

Expansion of gas with heat, CO_2 leaving solution, final yeast activity before it dies, and water turning to vapor.

8. Medium Find the hydration of a dough with 500 g flour and 375 g water.

Show answer

75%.

9. Hard Why does the no-knead method work without kneading?

Show answer

Over many hours, hydrated glutenin and gliadin slowly link into a gluten network on their own, and the gas bubbles stretch and align it; time replaces mechanical work.

10. Hard A recipe uses 0.25% yeast and rises in 15 hours at 70 °F. Estimate the time at 80 °F (about 5.5 °C warmer) using the doubling-per-10 °C rule.

    Show answer

    $2^{0.55} = 1.46$; $15/1.46 \approx 10$ hours.

11. Challenge Why does a loaf stop rising in the oven even though the gas keeps getting hotter?

    Show answer

    Once the crust dries and the starch and gluten set (about 150–180 °F inside the outer layers), the structure is rigid and cannot stretch; additional gas escapes through the crust instead.

COMMON MISTAKES

- Reaching into a 450 °F pot with bare wrists or thin mitts.
- Slicing before the loaf has cooled, which squashes the crumb.
- Adding extra flour to the wet no-knead dough, which makes a dense loaf.
- Taking the lid off too early, so the crust sets before the loaf rises.

Make it a game · Press Conference. Play the Fleischmann brothers at the 1876 Centennial Exhibition. Your parent is a skeptical baker asking about compressed yeast, reliable rising, oven spring and why hot dough expands. Answer in character with Charles's law and gas expansion. If you hesitate for five seconds, your parent gets a point. Swap roles after five questions.

Scripture. “Another parable spake he unto them; The kingdom of heaven is like unto leaven, which a woman took, and hid in three measures of meal, till the whole was leavened.” (Matthew 13:33, KJV)

A tiny amount of yeast, hidden in a large amount of flour, quietly transforms the whole. Jesus used this everyday kitchen wonder to show how His kingdom grows.

6.3 Sourdough: Wild Yeast, Lactic Acid Bacteria and the Gold Rush

OBJECTIVES

- Tell how sourdough fed miners in the California and Klondike gold rushes, and how USDA scientists identified its bacterium in 1971.
- Explain how wild yeasts and lactic acid bacteria share a starter, and use pH to track its acidity.
- Build and feed a starter for a week, recording rise and pH, and cook sourdough pancakes.

> **Warm-up.** Smell plain yogurt, buttermilk and a slice of sourdough bread (if you have them). What do they have in common? What kind of molecule do you think makes that sour smell?

WATCH

Secrets of Sourdough: Science on the SPOT | KQED

KQED · 8:04

https://www.youtube.com/watch?v=y5xOpss4j5E

> **WHEN TO WATCH**
> During session 1. Listen for the names of the two microbes in San Francisco sourdough and what each contributes.

BACKUP VIDEO

Building a Sourdough Starter

King Arthur Baking Company · 7:02

https://www.youtube.com/watch?v=S9hyqmROlMQ

Before you start your starter. A step-by-step guide to feeding a starter from scratch by weight.

KEY TERMS

sourdough starter

A mixture of flour and water in which wild yeasts and lactic acid bacteria grow together; used to leaven bread.

lactic acid bacteria

Bacteria (such as *Lactobacillus* species) that ferment sugars into lactic acid and sometimes acetic acid, souring the food.

symbiosis

Two kinds of organisms living together in a way that helps one or both.

discard

Starter removed before feeding so the starter does not grow out of control; it can be cooked into pancakes, crackers or waffles.

pH

A measure of acidity: $pH = -\log[H^+]$. Each step of 1 is a tenfold change.

CORE IDEAS

The story. When gold was found in California in 1848, tens of thousands of prospectors rushed west. Commercial yeast was scarce in the mining camps, but a crock of sour dough, fed with flour and water and kept warm, could leaven bread and flapjacks indefinitely. San Francisco became famous for its sourdough bread, and in the Yukon and Alaska gold rush of the 1890s, old-timers were nicknamed "sourdoughs" because they carried their starters with them, sometimes inside their coats to keep them from freezing.

How they figured it out. For a century no one knew exactly what lived in a San Francisco starter. In the late 1960s, USDA food scientists Leo Kline and T. F. Sugihara at the Western Regional Research Center in Albany, California, isolated the microbes from local bakeries' starters. In 1971 they described a new bacterium, which they named *Lactobacillus sanfranciscensis,* and a yeast that thrives alongside it. The bacterium prefers maltose (from the starch in flour), which the yeast does not use, so they do not compete for food, and the acid the bacteria make keeps out most other microbes.

The kitchen science. A starter begins with the wild yeasts and bacteria already present on flour. Fed with flour and water, it goes through stages: early bubbling

from many different microbes, then a quiet, sour period as acid builds, then a stable culture dominated by acid-tolerant yeasts and **lactic acid bacteria**. The yeasts make carbon dioxide to raise the dough. The bacteria make lactic acid (mild and creamy-sour) and acetic acid (sharper, vinegar-like), lowering the pH from about 6 to about 3.5–4. That acidity flavors the bread, slows staling and mold, and helps keep harmful microbes out. A healthy starter rises and falls predictably after each feeding. A pink or orange tint or fuzzy mold means it must be thrown away.

Let's cook. You will build a starter over about a week, logging its rise and pH, and use the discard to cook sourdough pancakes. The skill is **feeding by weight**: equal parts starter, flour and water (1 : 1 : 1).

PICTURE STUDY



California Gold Miners with a Long Tom, Unknown photographer, c. 1852 · Daguerreotype · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Daguerreotypes like this one are among the earliest photographs of the California Gold Rush. The “long tom” was a wooden trough in which miners washed gravel to catch gold.

Look closely

- Find the long tom. How would water and gravel move through it?
- Look at the miners’ clothes and tools. What was their daily work like?
- Look at the setting. How far might these men be from a bakery or a store?
- Count the men. How would they share cooking duties?

Talk about it

1. Why was a sourdough starter so valuable in a mining camp?
2. A starter had to be fed every day. What does that tell you about the miners’ routine?
3. What made sourdough safe to keep for months without refrigeration? Use the word pH.

> **Safety first.** Do not taste raw starter or batter (raw flour). Keep the starter covered loosely (gas must escape) and throw it away if you see pink, orange or fuzzy mold or smell something rotten rather than sour. The griddle is hot; use a spatula and keep handles turned in.

KITCHEN LAB

A Week in the Life of a Starter

You will grow a sourdough starter from flour and water, measure its rise and pH every day, and decide when it is ready, then cook pancakes from the discard.

You will need

- A clean quart glass jar with a loose lid, a rubber band
- Whole-wheat or rye flour (to start) and all-purpose flour (to feed)
- A digital scale, a spoon and a ruler
- pH test strips
- A griddle or large skillet and a spatula
- Your lab notebook

Sourdough Discard Pancakes

Serves About 12 pancakes (4 servings) · Prep 10 min · Cook 15 min

Ingredients

- 240 g (1 cup) sourdough starter discard
- 120 g (1 cup) all-purpose flour
- 240 mL (1 cup) milk
- 1 large egg
- 2 tablespoons sugar and 2 tablespoons melted butter
- ½ teaspoon salt and 1 teaspoon baking soda
- Butter or oil for the griddle; fruit or maple syrup to serve

Method

1. Whisk the starter, flour, milk, egg, sugar, melted butter and salt in a bowl until smooth. (Optional: cover and let stand 1 hour or refrigerate overnight for more flavor.)
2. Just before cooking, sprinkle the baking soda over the batter and stir gently; it will foam as it reacts with the starter’s acid. Do not taste the batter.

3. Heat the griddle over medium heat and grease it lightly. Pour ¼-cup portions.
4. Cook until bubbles form and the edges look dry, about 2 minutes; flip and cook 1–2 minutes more until golden and cooked through.
5. Serve warm. Wash the bowl and whisk; wipe the griddle when cool.

Allergy check: Contains wheat, milk and eggs. For milk-free, use a plant milk and oil (soy milk contains soy).

Steps

1. **Day 1.** Mix 50 g whole-wheat or rye flour with 50 g lukewarm water in the jar. Mark the level with a rubber band. Cover loosely. Record pH, smell and appearance.
2. **Days 2–7.** Each day at the same time, record the pH, the highest level the starter reached since the last feeding (look for the ring on the glass), and the smell. Then discard all but 50 g and feed with 50 g all-purpose flour and 50 g water (a 1 : 1 : 1 feeding). Save discard in a covered jar in the refrigerator for pancakes.
3. **Ready test.** The starter is ready when it at least doubles within 4–8 hours of feeding for two days in a row and smells pleasantly sour.
4. **Graph** pH and rise percentage against day.
5. **Cook** the discard pancakes, and watch the baking soda react with the acid.
6. **Conclusion.** Describe the stages your starter went through and explain them with the changing community of microbes and the falling pH.
7. Keep the starter in the refrigerator between bakes and feed it weekly; you will use it again for bread if you like.

Tips

- Starting with whole-wheat or rye flour gives the microbes more nutrients; switch to white flour for feeding.
- Chlorinated tap water can slow a starter; let tap water stand overnight or use filtered water.
- A layer of gray liquid on top (“hooch”) means the starter is hungry; stir it in or pour it off and feed.

Check your work

- ☐ I can explain how wild yeasts and lactic acid bacteria share a starter.
- ☐ I tracked a starter's rise and pH for a week and graphed them.
- ☐ I used starter discard in a cooked recipe and explained the baking-soda reaction.

LAB NOTEBOOK

1. Draw a microscope view of starter with yeast cells (round, budding) and lactobacilli (rods), labeling what each makes.
2. Graph pH and rise by day.
3. Write your feeding schedule and the pancake recipe in your own words.

KEY FORMULAS

$$\text{pH} = -\log[\text{H}^+] \qquad [\text{H}^+] = 10^{-\text{pH}}$$

$$\text{starter hydration} = \frac{m_{\text{water}}}{m_{\text{flour}}} \times 100\%$$

$$\text{rise }\% = \frac{h_{\text{peak}} - h_{\text{start}}}{h_{\text{start}}} \times 100\%$$

From history. Sourdough is far older than the gold rush: until commercial yeast became common in the 1800s, nearly all leavened bread in Europe was made with some form of sour starter or with yeast from other fermentations. Archaeologists have found evidence of leavened bread in ancient Egypt.

WORKED EXAMPLES

Example 1. A starter's pH falls from 6.0 on day 1 to 3.8 on day 7. By what factor has its hydrogen-ion concentration increased?

Show solution

1. $\dfrac{10^{-3.8}}{10^{-6.0}} = 10^{2.2} = 158.$

Answer: About 160 times more acidic.

Example 2. You feed 50 g of starter with 50 g flour and 50 g water. What is the hydration of the new starter (if the old starter was also 100% hydration), and what fraction of it is old starter?

Show solution

1. Old starter: 25 g flour + 25 g water. New: 75 g flour + 75 g water.
2. Hydration: $\frac{75}{75} = 100\%$. Old starter: $\frac{50}{150} = \frac{1}{3}$.

Answer: 100% hydration; one-third old starter (a 1 : 1 : 1 feeding).

Example 3. A starter in a jar rises from 4.0 cm to 9.2 cm at its peak. Find the rise percentage.

Show solution

1. $\frac{9.2 - 4.0}{4.0} \times 100\% = 130\%$.

Answer: 130%, more than doubled, a sign of a strong, active starter.

Example 4. Pancakes use 240 g of 100%-hydration starter discard plus 120 g flour and 240 g milk. How much total flour and liquid are in the batter, and what is its hydration (count milk as water)?

Show solution

1. Flour: $120 + 120 = 240$ g; liquid: $120 + 240 = 360$ g.
2. $\frac{360}{240} = 150\%$.

Answer: 150% hydration, a pourable batter, much wetter than bread dough.

PRACTICE

1. Easy Name the two kinds of microbes in a sourdough starter.

Show answer

Wild yeasts and lactic acid bacteria.

2. **Easy** What bacterium did Kline and Sugihara name in 1971?

   Show answer

   Lactobacillus sanfranciscensis (now often called *Fructilactobacillus sanfranciscensis*).

3. **Easy** Find $[H^+]$ at pH 4.

   Show answer

   10^{-4} mol/L

4. **Medium** How many times more acidic is pH 3.5 than pH 5.5?

   Show answer

   100 times.

5. **Medium** Why don't the yeast and the bacterium in San Francisco starter compete for food?

   Show answer

   The bacterium uses maltose, which that yeast does not use.

6. **Medium** A jar of starter rises from 5.0 cm to 11.5 cm. Find the rise.

   Show answer

   130%.

7. **Medium** Why does baking soda make discard pancakes fluffy?

   Show answer

   It reacts with the starter's acids to release carbon dioxide.

8. **Medium** Why were gold-rush prospectors called "sourdoughs"?

   Show answer

   They carried and kept sourdough starters to make bread and flapjacks in camps far from stores.

9. **Hard** You keep 40 g of starter and feed 1 : 2 : 2. How much flour and water, and what fraction of the new starter is old starter?

   Show answer

   80 g flour and 80 g water; $40/200 = 1/5$.

10. Hard Explain how acidity makes sourdough bread resist mold.

Show answer

Lactic and acetic acids lower the pH so that many molds and bacteria grow poorly; acetic acid in particular inhibits mold.

11. Challenge A starter's pH changes from 4.6 to 3.9 overnight. If 1 g of lactic acid (90 g/mol) lowers pH by about this much in 150 g of starter, estimate the moles of lactic acid produced.

Show answer

$1/90 = 0.011$ mol (about 11 mmol); the exact relationship depends on the starter's buffering, so this is an estimate.

COMMON MISTAKES

- Sealing the jar tightly, so gas builds up.
- Giving up on day 3 or 4 when the starter goes quiet; this is a normal stage.
- Keeping a starter with pink or orange streaks.
- Tasting raw starter or batter.

> **Make it a game · Starter Forecast.** Sketch a seven-day chart predicting how a sourdough starter's bubbles and acidity change each day. Show wild yeast and lactic acid bacteria and their symbiosis. Your parent asks three challenge questions, such as why pH falls and why discard is used. Tell how gold rush miners kept starters alive.

6.4 Lactic Fermentation: Captain Cook's Sauerkraut

OBJECTIVES

- Tell how Captain James Cook carried sauerkraut on his first Pacific voyage (1768–1771) to protect his crew's health.
- Explain how salt and lactic acid bacteria turn cabbage into sauerkraut, and why the pH must fall below 4.6.
- Make a jar of sauerkraut with 2% salt by mass and record its pH for three weeks.

> **Warm-up.** Taste a piece of fresh cabbage and (if you have it) a forkful of store-bought sauerkraut. How are they different? Where do you think the sour taste comes from, since no vinegar is added?

WATCH

The Science of Fermentation: Lactofermentation

Masala Lab · 10:55

https://www.youtube.com/watch?v=GQXa6MQvt7g

> **WHEN TO WATCH**
> During session 1. Copy the salt rule the host gives (salt as a percentage of the vegetables and water), and listen for why salt keeps harmful microbes out.

KEY TERMS

lactic fermentation

Fermentation by lactic acid bacteria that turns sugars into lactic acid, souring and preserving vegetables, milk and other foods.

brine

Salty water. In sauerkraut, salt draws water out of the cabbage to make its own brine.

anaerobic

Without oxygen. Keeping cabbage under brine shuts out air, which favors lactic acid bacteria and keeps out molds.

succession

The way one group of microbes gives way to another as conditions (acidity, salt) change.

pH 4.6

The acidity line below which *Clostridium botulinum* cannot grow; safely fermented sauerkraut falls to about pH 3.5.

CORE IDEAS

The story. On long voyages in the 1700s, sailors living on salt meat and hard biscuit developed scurvy (Lesson 1.5). When Lieutenant James Cook sailed HMS *Endeavour* to the Pacific in 1768, he carried thousands of pounds of sauerkraut, among other foods the Admiralty wanted tested. Sailors were suspicious of the strange German cabbage, so Cook, by his own account, had it served at the officers' table every day; when the men saw the officers enjoying it, they soon wanted it too. On that three-year voyage no sailor died of scurvy, a remarkable record for the time.

How they figured it out. Cook's success came from many measures together: frequent fresh food on shore, cleanliness, ventilation and fresh water, as well as sauerkraut. We now know that sauerkraut keeps some of cabbage's vitamin C, though less than fresh fruit, and that citrus is far richer. The great lesson of the voyage was that food and care could prevent scurvy; the full answer, vitamin C, came in the 1930s. The preservation method itself had been worked out by generations of European households: salt the cabbage, pack it tight, keep it under its brine, and wait.

The kitchen science. Sauerkraut is preserved by microbes and acid. Salt at about 2–2.5% of the cabbage's mass draws water out of the cells by osmosis to make a brine and slows many spoilage bacteria. Lactic acid bacteria, already present on the leaves, tolerate salt and thrive without air under the brine. They ferment the cabbage's sugars into lactic acid in a **succession**: first *Leuconostoc* species, which also make carbon dioxide (the bubbling) and acetic acid, then more acid-tolerant *Lactobacillus* species. The pH falls from about 6 to about 3.5 over a few weeks. Below pH 4.6, *Clostridium botulinum* cannot grow, and most other harmful bacteria are stopped. Keeping the cabbage fully submerged prevents molds and yeasts, which need air, from growing on top. Temperature matters: about 70–75 °F (21–24 °C) gives the best flavor in about 3–4 weeks.

Let's cook. You will make a quart of sauerkraut using the method and salt ratio of tested home-preservation guides. The skill is **weighing salt as a percentage** and keeping everything clean and submerged.

PICTURE STUDY



Captain James Cook, Nathaniel Dance, 1776 · Oil on canvas · National Maritime Museum, Greenwich, London

Image: Wikimedia Commons, public domain

Nathaniel Dance painted Cook in 1776, just before his third and last voyage. Cook rose from a farm laborer's son to one of the greatest navigators and mapmakers in history.

Look closely

- Find the chart on the table. What is he pointing to?
- Look at his uniform. What rank does it suggest?
- Look at his face and posture. What qualities would a captain of a three-year voyage need?

Talk about it

1. Cook served sauerkraut at the officers' table first. Why was that a wise way to change the crew's habits?
2. Why would preserved foods be so important on a voyage of several years?
3. What foods would you choose for a long voyage today, and why?

> **Safety first.** Start with very clean hands, jars and tools, and use only clean, fresh cabbage. Keep the cabbage completely under the brine. Throw the batch away if you see pink, black or fuzzy mold, if it smells rotten, or if it turns slimy. Ferment at room temperature (60–75 °F), then refrigerate. Do not can sauerkraut unless an adult follows a tested NCHFP recipe.

KITCHEN LAB

Three Weeks of Sauerkraut

You will make a quart of sauerkraut by weight and follow its fermentation with pH strips and daily observations until it is sour and stable.

You will need

- A clean wide-mouth quart jar and a smaller jar or zip-top bag of brine to use as a weight
- A digital scale, a large bowl, a chef's knife and a cutting board
- pH test strips
- A dish or tray to catch overflow
- A thermometer for the room
- Your lab notebook

Homemade Sauerkraut

Serves About 1 quart (8–10 servings as a side) · Prep 30 min · Ferment 3–4 weeks

Ingredients

- 1 medium green cabbage (about 1 kg before trimming)
- Salt at 2–2.25% of the trimmed cabbage's mass (about 18–22 g): canning or fine sea salt without iodine or anti-caking agents
- Optional: 1 teaspoon caraway seeds
- If needed, 2% brine: 10 g salt dissolved in 500 g water

Method

1. Wash your hands, the jar, bowl, knife and board in hot soapy water and rinse well.
2. Remove the outer leaves of the cabbage and save one clean leaf. Quarter the cabbage, cut out the core and slice it thin (about ⅛ inch).
3. Weigh the sliced cabbage and calculate and weigh the salt. Toss them together in the bowl and squeeze and massage for 5–10 minutes until the cabbage is limp and juicy.

4. Pack the cabbage firmly into the jar a handful at a time, pressing down so the juice rises over it. Leave 1–2 inches of headspace. Pour in any juice left in the bowl.
5. Lay the saved leaf on top and press the small jar or a brine-filled bag onto it so all the cabbage stays under the liquid. Add 2% brine if needed to cover. Cover loosely and set the jar on a tray.
6. Ferment at 65–75 °F away from sunlight. Check daily that the cabbage is submerged; skim any white film from the surface.
7. After 3–4 weeks, when it is sour and the pH is at or below about 3.6, cover and refrigerate. It keeps for months in the refrigerator.

Allergy check: Contains none of the major allergens. Sauerkraut is high in salt; serve it as a side.

Steps

1. **Hypothesis.** Predict how the pH will change over three weeks, and when it will cross 4.6.
2. **Day 0.** Record the cabbage mass, salt mass and percentage, room temperature, and the pH of the juice.
3. **Daily for week 1, then every other day.** Record the pH of a few drops of brine (use a clean spoon), bubbling, color, smell and room temperature.
4. **Graph** pH against time and mark the 4.6 line.
5. **Taste** (only after the pH is below 4.6 and nothing looks or smells wrong) at weeks 2 and 3, and record how sourness and crunch change.
6. **Serve** your sauerkraut with a family meal, such as sausages and potatoes.
7. **Conclusion.** Explain your pH curve with the succession of lactic acid bacteria and the role of salt and air.
8. Wash all tools in hot soapy water after each check.

Tips

- Weigh the salt; too little lets soft, spoiled kraut develop, too much stops fermentation.
- Cooler rooms (60–65 °F) ferment slowly but give crisp, clean flavor; above 75 °F kraut can soften.

- Bubbling and a little overflow in the first days are signs of healthy fermentation.

Check your work

- ☐ I can explain lactic fermentation, the role of salt and the importance of keeping air out.
- ☐ I can calculate salt by percentage and explain the pH 4.6 line.
- ☐ I made sauerkraut and tracked its pH over three weeks.

LAB NOTEBOOK

1. Draw the jar in cross-section: cabbage, brine, the weight, the headspace, and microbes at work.
2. Graph pH against days, marking the 4.6 line and when you first tasted.
3. Make a timeline of the microbial succession.

KEY FORMULAS

$$m_{\text{salt}} = 0.02 \times m_{\text{cabbage}}$$

$$\text{salt \% of brine} = \frac{m_{\text{salt}}}{m_{\text{salt}} + m_{\text{water}}} \times 100\%$$

From history. Fermented cabbage was eaten in China more than two thousand years ago and became a staple of northern and eastern Europe; Korean kimchi is a spicy relative. The word *Sauerkraut* is German for “sour cabbage.”

WORKED EXAMPLES

Example 1. A trimmed head of cabbage weighs 920 g. How much salt for 2.0% and for 2.25% by mass?

Show solution

1. $0.020 \times 920 = 18.4$ g; $0.0225 \times 920 = 20.7$ g.

Answer: About 18–21 g of salt, roughly 1 tablespoon of fine salt. Weigh it; salt grains vary in size.

Example 2. The National Center for Home Food Preservation's sauerkraut uses about 3 tablespoons of canning salt (about 52 g) for 5 lb of cabbage. Find the salt percentage.

Show solution

1. $5\text{ lb} = 5 \times 453.6\text{ g} = 2268\text{ g}$.
2. $\dfrac{52}{2268} \times 100\% = 2.3\%$.

Answer: About 2.3%, consistent with the 2–2.5% range.

Example 3. If the cabbage doesn't make enough brine to cover it, cooks add a 2% brine. How much salt goes into 500 g of water for a 2% brine?

Show solution

1. $\dfrac{m}{m + 500} = 0.02 \;\Rightarrow\; m = 0.02m + 10 \;\Rightarrow\; m = 10.2\text{ g}$.

Answer: About 10 g of salt in 500 g of water.

Example 4. Sauerkraut's pH falls from 6.2 to 3.6. What is the ratio of hydrogen-ion concentrations?

Show solution

1. $10^{6.2 - 3.6} = 10^{2.6} = 398$.

Answer: About 400 times more acidic.

PRACTICE

1. Easy What acid gives sauerkraut its sour taste?

   Show answer

   Lactic acid (with some acetic acid).

2. Easy How much salt for 1,200 g of cabbage at 2%?

   Show answer

   24 g.

3. Easy Why must the cabbage stay under the brine?

Show answer

To keep out air, which molds and yeasts need, and to favor lactic acid bacteria.

4. Medium What is special about pH 4.6?

Show answer

Below it, *Clostridium botulinum* cannot grow or make toxin.

5. Medium How did Cook get his sailors to eat sauerkraut?

Show answer

He had it served daily to the officers; the men wanted it once they saw the officers eating it.

6. Medium Find the salt percentage of 15 g of salt in 750 g of cabbage.

Show answer

2.0%.

7. Medium Why does a jar of new sauerkraut bubble in the first days?

Show answer

Early lactic acid bacteria (*Leuconostoc*) produce carbon dioxide as well as acid.

8. Medium Name two signs that a batch must be thrown away.

Show answer

Pink, black or fuzzy mold; a rotten smell; slimy texture.

9. Hard A recipe uses 2.5 kg of cabbage. How much salt at 2.25%, and how many tablespoons if 1 tablespoon of the salt weighs 17 g?

Show answer

56.3 g; about 3.3 tablespoons.

10. Hard Why does sauerkraut keep crisp and safe for months in the refrigerator?

Show answer

Its low pH stops most harmful microbes, and cold slows the remaining fermentation and softening enzymes.

11. **Challenge** Sauerkraut was less effective against scurvy than citrus. Suggest two reasons, using what you know about vitamin C.

    Show answer

    Cabbage has less vitamin C than citrus to begin with, and vitamin C is gradually destroyed by oxidation and heat during storage and cooking; much is also lost in the brine if it is discarded.

COMMON MISTAKES

- Using iodized salt or table salt with anti-caking agents, which can cloud the brine.
- Measuring salt by volume instead of weight.
- Leaving cabbage exposed above the brine.
- Sealing the jar tightly so gas cannot escape.

> **Make it a game · Salt the Cabbage.** Your parent gives you cabbage weights, such as 500, 800 and 1200 grams. Calculate the salt needed at about two percent for each, in your head or on paper, racing a timer. Then describe succession, the lactic acid bacteria that take over as pH drops toward 4.6. Tell why Captain Cook carried sauerkraut.

6.5 Vinegar and Acetic Acid: Dip Thy Morsel

OBJECTIVES

- Tell how vinegar appears in the story of Ruth, and how Pasteur showed in the 1860s that vinegar is made by living bacteria.
- Explain acetic acid, acidity and neutralization, and calculate the percentage of acetic acid in vinegar from the carbon dioxide released by baking soda.
- Measure the acidity of vinegar in a kitchen titration, and cook a sweet-and-sour chicken stir-fry.

> **Warm-up.** Put a few drops of vinegar, lemon juice, milk, baking-soda water and plain water on pH strips (or in red-cabbage water if you have it). Line them up from most acidic to least. Where does vinegar fall?

WATCH

06. Percentage of Ethanoic Acid in Vinegar

Pdst Chemistry · 4:27

https://www.youtube.com/watch?v=_Vw1N5xUl_Q

> **WHEN TO WATCH**
> During session 1, before your lab. Watch how a chemistry student measures the acid in vinegar exactly; your kitchen method will use the same idea with simpler tools.

KEY TERMS

acetic acid

CH_3COOH, the acid in vinegar; household vinegar is about 5% acetic acid by mass.

acetic acid bacteria

Bacteria (*Acetobacter*) that use oxygen to oxidize ethanol into acetic acid; the “mother of vinegar” is a film of them.

neutralization

An acid reacting with a base to form water and a salt; with baking soda, carbon dioxide is also released.

titration

Measuring the amount of acid (or base) in a sample by adding a reactant of known strength until the reaction is just complete.

sweet and sour

A sauce that balances the sourness of vinegar against the sweetness of sugar or fruit.

CORE IDEAS

The story. When Ruth, a poor widow from Moab, gleaned barley in the fields of Bethlehem, the landowner Boaz noticed her kindness and faithfulness. At mealtime he invited her to sit with his reapers: "eat of the bread, and dip thy morsel in the vinegar." Bread dipped in a sour, refreshing vinegar was a common meal for field workers in the heat. Vinegar is one of the oldest foods people have made on purpose, used for flavor, for preserving and for cleaning in nearly every culture.

How they figured it out. For centuries vinegar makers knew that a slimy, leathery film, the "mother of vinegar," formed on the surface of good batches and could start new ones. In the 1860s Louis Pasteur studied it under the microscope and showed that the mother is a mass of living bacteria and that they need air: they work only at the surface, where oxygen is available. His studies (published in 1868) helped vinegar makers control their process and avoid spoiled batches.

The kitchen science. Vinegar is made in two fermentations. First, yeasts turn the sugars of a fruit juice or grain mash into ethanol (Lesson 6.1). Then **acetic acid bacteria** use oxygen to oxidize that ethanol into acetic acid: $C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$. Finished vinegar contains acetic acid and essentially no ethanol. Household distilled white and cider vinegars are standardized to about 5% acidity (pH about 2.4–2.6), the strength tested canning and pickling recipes require. Acetic acid is a weak acid: only a small fraction of its molecules release H^+ ions at any moment. With baking soda it is **neutralized**: $CH_3COOH + NaHCO_3 \rightarrow NaCH_3COO + H_2O + CO_2$. Because every 60.05 g of acetic acid releases 44.01 g of carbon dioxide, weighing the CO_2 that escapes lets you calculate how much acid was in the vinegar. In cooking, acid brightens flavors, balances sweetness and fat, firms vegetables and tenderizes the surface of meat.

Let's cook. You will cook a sweet-and-sour chicken stir-fry with a sauce balanced by taste and by ratio. The skill is **balancing sour and sweet**: adjusting a sauce a little at a time and tasting (once the chicken is cooked) until neither overwhelms the other.

PICTURE STUDY



Ruth in Boaz's Field, Julius Schnorr von Carolsfeld, 1828 · Oil on canvas · National Gallery, London

Image: Wikimedia Commons, public domain

The German painter Julius Schnorr von Carolsfeld, known for his illustrated Bible, painted the moment Boaz first meets Ruth gleaning in his field, from Ruth chapter 2.

Look closely

- Find Ruth. What has she gathered?
- Find Boaz. What does his gesture tell you about how he treats her?
- Find the reapers in the background. What tools are they using?
- Imagine the noon meal. Where would the workers sit to eat their bread and vinegar?

Talk about it

1. Boaz shared his workers' meal with a poor stranger. What does that teach about hospitality?
2. Why might bread dipped in vinegar have been refreshing to workers in a hot field?
3. How is Ruth's gleaning connected to the painting of the gleaners you saw in Lesson 3.3?

> **Safety first.** The vinegar titration is safe, but it foams; work in a large cup on a tray. Never mix vinegar with bleach (Lesson 1.3). The stir-fry uses a very hot pan: work with care, keep a lid nearby, and cook chicken to 165 °F (74 °C).

KITCHEN LAB

How Strong Is Your Vinegar?

You will measure the acetic acid in two vinegars by weighing the carbon dioxide released by baking soda, compare your results with the labels, and then cook with vinegar.

You will need

- A digital scale (0.1 g if possible)
- Two large plastic cups and a teaspoon
- Distilled white vinegar and apple cider or rice vinegar
- Baking soda
- pH strips
- A large skillet or wok and a lid
- Your lab notebook

Sweet-and-Sour Chicken Stir-Fry

Serves 4–5 · Prep 25 min · Cook 15 min

Ingredients

- 1¼ lb (570 g) boneless chicken breast or thighs, cut into 1-inch pieces
- 1 tablespoon soy sauce and 1 tablespoon cornstarch (for the chicken)
- 2 tablespoons vegetable oil, divided
- 1 red and 1 green bell pepper, cut into 1-inch pieces; 1 small onion, cut into wedges
- 1 can (20 oz) pineapple chunks in juice, drained (save ½ cup juice)
- **Sauce:** ½ cup reserved pineapple juice, ¼ cup rice vinegar or cider vinegar, ¼ cup (50 g) brown sugar, 3 tablespoons ketchup, 1 tablespoon soy sauce, 1 tablespoon cornstarch
- Cooked rice for serving

Method

1. Start the rice. Whisk the sauce ingredients together.

2. Toss the chicken with 1 tablespoon soy sauce and the cornstarch.
3. Heat 1 tablespoon oil in the skillet over medium-high heat. Add the chicken in one layer and cook 4–6 minutes, turning, until browned and 165 °F (74 °C) inside. Move to a clean plate.
4. Add the remaining oil, the onion and peppers, and stir-fry 3 minutes until crisp-tender. Add the pineapple.
5. Stir the sauce and pour it in; stir until thick and glossy, about 1–2 minutes. Return the chicken and toss.
6. Taste the sauce (now cooked) and adjust: a splash of vinegar if too sweet, a pinch of sugar if too sharp. Serve over rice.
7. Wash the board used for raw chicken in hot soapy water and sanitize it.

Allergy check: Contains soy and wheat (soy sauce). For wheat-free, use tamari labeled gluten-free and check the ketchup.

Steps

1. **pH.** Measure the pH of each vinegar.
2. **Set up.** Put a cup on the scale and weigh 100.0 g of vinegar into it. In a second cup weigh 10.0 g of baking soda. Record the combined mass of both cups and contents.
3. **React.** Add the baking soda to the vinegar a teaspoon at a time (it will foam), swirling gently. When all is added and the foaming has stopped (about 5 minutes, swirling now and then), weigh both cups together again.
4. **Calculate** the mass of CO_2 lost, then the mass and percentage of acetic acid.
5. **Repeat** with the second vinegar, and with a second trial of the first if you have time.
6. **Compare** your results with the labels (“5% acidity” or “4.3% acidity”) and calculate the percent error.
7. **Cook** the stir-fry and balance the sauce.
8. **Conclusion.** Explain the reaction and two sources of error (for example, CO_2 staying dissolved, or water vapor escaping).

Tips

- Swirling helps dissolved CO_2 escape; a warm room helps too.

- Use a cup much larger than the vinegar so the foam does not overflow and carry liquid away.
- Rice vinegar is milder (about 4–4.5% acidity) than distilled white vinegar (5%).

Check your work

- ☐ I can explain how vinegar is made by microbes and what acetic acid is.
- ☐ I measured the acid in vinegar with a neutralization reaction and calculated its percentage.
- ☐ I cooked a sauce that balances sour and sweet.

LAB NOTEBOOK

1. Write the neutralization equation and label the acid, base, salt, water and gas.
2. Record your titration data, calculations and percent error for each vinegar.
3. Make a pH chart of the kitchen liquids you tested.

KEY FORMULAS

$$\mathrm{CH_3COOH} + \mathrm{NaHCO_3} \rightarrow \mathrm{NaCH_3COO} + \mathrm{H_2O} + \mathrm{CO_2}$$

$$m_{\text{acetic acid}} = m_{\mathrm{CO_2}} \times \frac{60.05}{44.01}$$

$$\%\,\text{acid} = \frac{m_{\text{acetic acid}}}{m_{\text{vinegar}}} \times 100\%$$

From history. Vinegars have been made around the world from apples, rice, dates, grains, sugarcane, coconut and many other foods. Today most distilled white vinegar is made from corn-based ethanol, and it is standardized at 5% acidity for home use.

WORKED EXAMPLES

Example 1. You add excess baking soda to 100.0 g of vinegar. The mass of the cup and contents drops by 3.6 g as $\mathrm{CO_2}$ escapes. Find the acetic acid percentage.

Show solution

1. Acetic acid: $3.6\ \text{g} \times \frac{60.05}{44.01} = 4.9\ \text{g}$.
2. $\%\,\text{acid} = \frac{4.9}{100.0} \times 100\% = 4.9\%$.

Answer: About 4.9%, very close to the 5% on the label.

Example 2. How much baking soda (84.01 g/mol) is needed to neutralize all the acid in 100 g of 5.0% vinegar?

Show solution

1. Acid: $5.0\ \text{g} \div 60.05\ \text{g/mol} = 0.0833\ \text{mol}$.
2. Baking soda (1 : 1): $0.0833 \times 84.01 = 7.0\ \text{g}$.

Answer: About 7.0 g. Use about 10 g so there is clearly an excess.

Example 3. Vinegar has a pH of about 2.4 and lemon juice about 2.2. Which is more acidic, and by what factor?

Show solution

1. $10^{2.4-2.2} = 10^{0.2} = 1.6$.

Answer: Lemon juice, about 1.6 times higher in H^+.

Example 4. A sauce uses ¼ cup (60 mL) rice vinegar (4.3% acid, density 1.01 g/mL) and ¼ cup (50 g) sugar. Find the mass ratio of sugar to acetic acid.

Show solution

1. Acid: $60 \times 1.01 \times 0.043 = 2.6\ \text{g}$.
2. Ratio: $\dfrac{50}{2.6} = 19$.

Answer: About 19 g of sugar for every gram of acetic acid; that is how strong a sour taste acetic acid has.

PRACTICE

1. Easy What acid is in vinegar, and about what percentage is household vinegar?

   Show answer

   Acetic acid; about 5%.

2. Easy What gas forms when vinegar reacts with baking soda?

   Show answer

   Carbon dioxide.

3. **Easy** What did Pasteur show the "mother of vinegar" to be?

   Show answer

   A film of living bacteria that need air.

4. **Medium** 100.0 g of vinegar loses 3.2 g of CO_2 with excess baking soda. Find the acetic acid percentage.

   Show answer

   $3.2 \times 60.05/44.01 = 4.4$ g; 4.4%.

5. **Medium** How much baking soda neutralizes 200 g of 5% vinegar?

   Show answer

   Acid 10 g = 0.167 mol; baking soda 14.0 g.

6. **Medium** Why do tested pickling and canning recipes specify vinegar of at least 5% acidity?

   Show answer

   So that the food reaches a safely low pH; weaker or homemade vinegar of unknown strength may not.

7. **Medium** Find the percent error if you measured 4.6% and the label says 5.0%.

   Show answer

   8%.

8. **Medium** Why is acetic acid called a weak acid?

   Show answer

   Only a small fraction of its molecules release H^+ ions in water at any moment.

9. **Hard** In Ruth 2:14, Boaz tells Ruth to dip her bread in vinegar. Give two reasons, from food science, that vinegar was a practical food for field workers.

   Show answer

   It kept without spoiling (its acidity prevents growth of most microbes),; and its sour taste was refreshing and flavored plain bread.

10. Hard Some CO_2 stays dissolved in the cup. Will your calculated acid percentage be too high or too low? Explain.

Show answer

Too low; the mass lost (CO_2 escaped) is less than the CO_2 actually produced.

11. Challenge A cook dilutes 5% vinegar with an equal mass of water for a quick pickle brine. Find the new acid percentage, and explain why such brines are for refrigerator pickles only.

Show answer

2.5%. Tested canning recipes require specific acid levels and processing; a weak brine may not keep the pH low enough for shelf storage.

COMMON MISTAKES

- Using a small cup so the foam overflows and liquid is lost.
- Weighing before the reaction is finished.
- Mixing vinegar with bleach for “stronger” cleaning.
- Adding all the vinegar to a sauce at once instead of tasting and adjusting.

Make it a game · Fizz Count. Pour a spoonful of vinegar into a cup. Predict how many pinches of baking soda stop the fizzing, then add pinches one at a time and count. Repeat with a different vinegar and compare. Explain neutralization of acetic acid and why titration works this way. Tell the story of vinegar in Ruth and how Pasteur found its bacteria.

Scripture. “And Boaz said unto her, At mealtime come thou hither, and eat of the bread, and dip thy morsel in the vinegar: and she sat beside the reapers: and he reached her parched corn, and she did eat, and was sufficed, and left.” (Ruth 2:14, KJV)

Boaz shared his simple meal with a poor stranger at his table. Vinegar, bread and parched grain were plain foods, made rich by hospitality.

UNIT 6

Microbes I: Fermentation

Some of the oldest and best foods are made by microbes: bread, yogurt, cheese, sauerkraut, pickles and vinegar. In this unit you will learn how yeasts and bacteria change food by fermentation, how their products raise bread, sour vegetables and preserve food, and how cooks keep the good microbes working and the harmful ones out.

The stories follow Louis Pasteur proving that fermentation is alive, the Fleischmann brothers bringing reliable yeast to American kitchens, the gold-rush "sourdoughs" and the USDA scientists who named their bacterium, Captain Cook's sauerkraut, and Ruth at Boaz's table. You will measure yeast activity, oven spring, a starter's pH, sauerkraut's pH over three weeks and the acid in vinegar, and you will bake a honey whole-wheat loaf and a no-knead crusty loaf, cook sourdough pancakes, ferment sauerkraut and make a sweet-and-sour stir-fry.

PREREQUISITES

- Unit 3: sugars and starch
- Unit 4: gluten and baker's percentages
- Comfort with logarithms for pH (taught as needed) and with moles and molar mass (taught in Lessons 2.1 and 4.1)

MASTERY CHECKLIST

- ☐ I can explain how Pasteur showed fermentation is caused by living microbes.
- ☐ I can use the yeast fermentation equation and molar volume to calculate CO_2 produced.
- ☐ I can explain oven spring with the gas laws, steam and the setting of starch and gluten.
- ☐ I can explain how wild yeasts and lactic acid bacteria make sourdough and sauerkraut, and why pH 4.6 matters.
- ☐ I can calculate salt percentages and pH ratios, and measure acid in vinegar by neutralization.
- ☐ I baked two breads and made a starter, sauerkraut and a sweet-and-sour dish safely.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **National Center for Home Food Preservation: Fermenting**: Free. Tested methods for sauerkraut and fermented pickles from the University of Georgia; see the "Ferment" section for Lesson 6.4.
- **King Arthur Baking: Sourdough Guides**: Free. Feeding schedules, troubleshooting and recipes for Lesson 6.3.
- **pH test strips**: Used in Lessons 6.3–6.5. Inexpensive strips covering about pH 2–9 are enough.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

6.1 Pasteur Proves Fermentation Is Alive — 3 sessions of 50–90 minutes (plus rising time)

6.2 Yeast Biology and Oven Spring: The Fleischmann Brothers
3 sessions of 50–90 minutes (plus 12–18 hours of rising)

6.3 Sourdough: Wild Yeast, Lactic Acid Bacteria and the Gold Rush
3 sessions of 50–90 minutes (plus a week of feeding)

6.4 Lactic Fermentation: Captain Cook's Sauerkraut
3 sessions of 50–90 minutes (plus 3–4 weeks of fermenting)

6.5 Vinegar and Acetic Acid: Dip Thy Morsel — 3 sessions of 50–90 minutes

Unit 6 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **8 pts**
   Describe what Pasteur saw in the Lille vats and what he concluded about fermentation.

2. **7 pts**

   Write the overall equation for what yeast does to glucose in dough, and find the CO_2 volume at 25 °C from 27.0 g of glucose.

3. **5 pts**

   What happens to yeast at 40 °F, 90 °F and 140 °F?

4. **6 pts**

   Gas in dough at 24 °C is heated to 100 °C. Find the expansion factor and explain why real oven spring is often greater.

5. **5 pts**

   A loaf rises from 6.0 cm to 9.9 cm in the oven. Find the oven spring.

6. **6 pts**

   Write the baker’s percentages for 500 g flour, 400 g water, 10 g salt and 2 g yeast.

7. **6 pts**

   Explain why the yeast and bacterium of San Francisco sourdough coexist.

8. **6 pts**

   A starter’s pH drops from 5.8 to 3.8. By what factor did $[H^+]$ change?

9. **6 pts**

   How much salt for 1,600 g of cabbage at 2.25%?

10. **7 pts**

    Explain the roles of salt, lack of air, and lactic acid bacteria in making sauerkraut safe.

11. **5 pts**

    How did Captain Cook persuade his sailors to eat sauerkraut?

12. **7 pts**

    100.0 g of vinegar with excess baking soda loses 3.5 g of CO_2. Find the acetic acid percentage.

13. **5 pts**

    Why must vinegar for tested pickling recipes be at least 5% acidity?

14. **6 pts**

    Name three signs that a ferment must be discarded.

15. **15 pts**

    Short essay (6–8 sentences): Compare yeast bread, sourdough and sauerkraut as fermented foods. For each, name the microbes, the main products and what those products do to the food, and explain one thing the cook does to help the right microbes win.

ANSWER KEY

1. Yeast cells in good vats and rod-shaped microbes in spoiled ones; fermentation is caused by living microorganisms, each kind of fermentation by its own microbe.
2. $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$. $27.0/180.2 = 0.150$ mol; CO_2 $0.300 \times 24.5 = 7.35$ L.
3. Very slow; works well; killed.
4. $373/297 = 1.26$. CO_2 also comes out of solution, yeast works until it dies, and water turns to vapor.
5. 65%.
6. 100, 80, 2, 0.4.
7. The bacterium uses maltose, which that yeast does not, so they do not compete; the bacteria's acid keeps out other microbes.
8. 100 times.
9. 36 g.
10. Salt draws out water to make brine and slows spoilage bacteria; keeping cabbage submerged excludes air, stopping molds and favoring lactic acid bacteria; the bacteria make lactic acid, dropping the pH below 4.6 so botulism and most pathogens cannot grow.
11. He had it served to the officers every day; seeing the officers enjoy it, the crew wanted it too.
12. $3.5 \times 60.05/44.01 = 4.8$ g; 4.8%.
13. To ensure the pickled food reaches a safely low pH.
14. Pink, orange or black color; fuzzy mold; rotten (not sour) smell; slimy texture.
15. Answers vary. Full credit for: bread, baker's yeast, CO_2 (rise) and a little ethanol (flavor, baked off), cook controls temperature and time; sourdough, wild yeasts plus lactic acid bacteria, CO_2 plus lactic and acetic acids (rise, flavor, keeping), cook feeds regularly; sauerkraut, lactic acid bacteria, lactic acid (sourness, preservation below pH 4.6), cook weighs salt and keeps cabbage under brine.

UNIT PROJECT: THE FERMENTATION LOG

Keep a four-week fermentation log for two ferments running at the same time: your sourdough starter (or a batch of yogurt or a second sauerkraut) and your sauerkraut. Record date, temperature, pH, appearance, smell, and every feeding or check, with photographs or sketches, and graph pH over time for both on the same axes.

Finish with a two-page report comparing the two ferments: the microbes involved, the products they make, why each became safe, what you would change, and one family meal that used your fermented foods, with a word of thanks.

LOOK FOR	WHAT IT MEANS
Safety and cleanliness	Clean tools, correct salt by weight, ferments kept submerged or fed, spoiled batches discarded.
Complete log	Regular, honest entries with dates, temperatures and pH.
Graph	Both pH curves on one labeled graph with the 4.6 line marked.
Science explanation	Correct use of fermentation, lactic acid bacteria, yeast, pH and succession.
Reflection	Thoughtful comparison, improvements and the family meal.

UNIT 7

Microbes II: Food Safety

The same microscopic world that raises bread and sours cabbage also contains pathogens: bacteria, viruses and parasites that can cause serious illness. This unit is about keeping them out of food: what they are, how they grow, how outbreaks are traced, and the systems and habits that prevent them, from handwashing and thermometers to HACCP and the cold chain.

The stories follow Daniel Salmon and Theobald Smith's bacillus, Fanny Hesse's kitchen agar, John Snow's map and the 1993 hamburger outbreak, the Pillsbury and NASA scientists who invented HACCP for astronauts, and Frederick McKinley Jones's truck refrigerator. The labs trace a simulated germ, grow sealed cultures from kitchen surfaces, compare burger color with temperature, write and follow a HACCP plan, and race two cooling methods against the clock. The recipes are chicken fajitas, chicken salad, hamburgers, chicken and rice soup and a big pot of chili.

PREREQUISITES

- Unit 1: thermometer calibration, safe temperatures, lab safety
- Unit 6: microbes, fermentation and pH
- Exponents and logarithms (powers of 2 and 10), taught as needed

MASTERY CHECKLIST

- ☐ I can name the major foodborne pathogens and distinguish bacteria, viruses and parasites.
- ☐ I can describe bacterial growth, apply FAT TOM, and calculate growth with $N = N_0 \cdot 2^{t/g}$.
- ☐ I can calculate attack rates and relative risk and explain how outbreaks are traced.
- ☐ I can explain HACCP's seven principles and write a HACCP plan.
- ☐ I can apply the two-stage cooling rule and Newton's law of cooling.
- ☐ I prevented cross-contamination and cooked and cooled foods to safe temperatures.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **Partnership for Food Safety Education: Fight BAC!**: Free. Printable Clean, Separate, Cook, Chill materials for posting in your kitchen.
- **FDA: Food Code**: Free on the FDA website. The model code for restaurants, including the cooling rules and HACCP guidance used in Lessons 7.4–7.5.
- **A state food-handler course**: Optional. Many states offer an online food-handler card for a small fee; this unit covers much of what the test asks.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

7.1 Bacteria, Viruses and Parasites: Salmon and Smith's Bacillus
3 sessions of 50–90 minutes

7.2 Growth Curves and FAT TOM: Fanny Hesse's Agar
3 sessions of 50–90 minutes (plus 3–5 days of observation)

7.3 Outbreak Detectives: John Snow to E. coli O157:H7 3 sessions of 50–90 minutes

7.4 HACCP: Safe Food for Astronauts 3 sessions of 50–90 minutes

7.5 The Cold Chain and Safe Leftovers: Frederick McKinley Jones
3 sessions of 50–90 minutes

Unit 7 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   Name one bacterium, one virus and one parasite that can be carried by food, with a typical source for each.

2. **5 pts**

   A cutting board has 3×10^6 bacteria. After a 4-log reduction, how many remain? What percentage were killed?

3. **6 pts**

   Explain why washing hands cannot make it safe for a person with norovirus to cook for others.

4. **6 pts**

   What did Fanny Hesse contribute to microbiology, and why did it work?

5. **7 pts**

   200 bacteria double every 20 minutes. How many after 3 hours? How long to reach 2×10^6?

6. **6 pts**

   Name the six FAT TOM factors and one way a cook controls each.

7. **7 pts**

   At a picnic, 45 ate the egg salad (27 ill) and 35 did not (4 ill). Find both attack rates and the relative risk. Is egg salad the likely source?

8. **6 pts**

   Describe how John Snow showed that the Broad Street pump spread cholera.

9. **6 pts**

   Why must ground beef be cooked to 160 °F while a whole steak is safe at 145 °F with a rest? Why can’t you judge doneness by color?

10. **5 pts**

    Why did the Pillsbury team design HACCP instead of testing finished space food?

11. **7 pts**

    List the seven HACCP principles.

12. **6 pts**

    A HACCP log shows cooked chicken at 158 °F and a refrigerator at 45 °F. Give the corrective action for each.

13. **7 pts**

    Chili at 135 °F is in an ice bath at 35 °F with k = 0.015 per minute. Find its temperature at 2 hours. Does it meet the first-stage rule?

14. **5 pts**

    What did Frederick McKinley Jones invent, and why did it matter?

15. **15 pts**

    Short essay (6–8 sentences): Plan a safe church potluck for 50 people. Explain how you would control pathogens at each stage (shopping, preparing, cooking, serving, leftovers) using FAT TOM, safe temperatures, cross-contamination rules and the cooling rule.

ANSWER KEY

1. Bacterium: *Salmonella* (poultry, eggs). Virus: norovirus (sick food handlers). Parasite: *Toxoplasma* or *Trichinella* (undercooked meat). Other correct answers accepted.
2. 300; 99.99%.
3. They shed enormous numbers of virus particles and only a few are needed to infect; a 2-log reduction from washing still leaves far more than an infectious dose.
4. She suggested agar as a solid culture medium; it stays solid at body temperature and few bacteria digest it.
5. $200 \cdot 2^9 = 102{,}400$; $\log_2(10^4) = 13.3$ generations, about 4.4 h.
6. Food (choose and handle high-risk foods carefully), Acidity (vinegar, pH below 4.6), Temperature (keep out of 40–140 °F), Time (2-hour rule), Oxygen (vacuum packing; note some bacteria need none), Moisture (drying, salt, sugar).
7. 60% and 11.4%; RR 5.3. Yes, very likely.
8. He mapped deaths, found them clustered near the pump, studied exceptions (nearby workers with their own well, a distant woman who drank the pump's water), and had the handle removed; the well was found to be contaminated by a cesspool.
9. Grinding spreads surface bacteria throughout; color is unreliable because some burgers brown before reaching 160 °F and some stay pink after.
10. Testing would destroy most of the food and still could not prove every package safe; controlling each step prevents hazards.
11. Hazard analysis; critical control points; critical limits; monitoring; corrective actions; verification; records.
12. Keep cooking to 165 °F and re-check; check the refrigerator (door, thermostat), move or evaluate foods that warmed, and record actions.
13. $35 + 100e^{-1.8} = 35 + 16.5 = 51.5$ °F; yes, below 70 °F.
14. A practical refrigeration unit for trucks (patented 1940); it made long-distance refrigerated transport possible and helped build the cold chain.
15. Answers vary. Full credit for: cold foods kept at or below 40 °F and hot at or above 140 °F; separate boards and hand washing; thermometers and correct temperatures (165, 160, 145 °F); the 2-hour (1-hour above 90 °F) rule while

serving; shallow containers and the two-stage cooling rule for leftovers; reheating to 165 °F; sick people not cooking.

UNIT PROJECT: OUR FAMILY FOOD-SAFETY PLAN

Write a HACCP-style food-safety plan for your own kitchen: a one-page hazard analysis of how food flows through your home (shopping, storage, preparation, cooking, serving, leftovers), the critical control points and limits for each, and a week-long log of refrigerator and freezer temperatures and of every meat and leftover temperature you check.

Then audit one family meal from shopping to leftovers against your plan, correct any problems you find, and make a laminated (or plastic-sleeved) card for the refrigerator door with the safe temperatures and cooling rules. Present your plan to your family at a meal.

LOOK FOR	WHAT IT MEANS
Hazard analysis	Covers biological, chemical and physical hazards at each step of your kitchen's food flow.
CCPs and limits	A few true CCPs with correct, measurable limits and corrective actions.
Records	A complete, honest week-long temperature log.
Audit and corrections	Real problems found and fixed, with notes.
Communication	A clear, accurate refrigerator card and a plan your family can follow.

7.1 Bacteria, Viruses and Parasites: Salmon and Smith's Bacillus

OBJECTIVES

- Tell how Daniel Salmon and Theobald Smith isolated the bacterium later named *Salmonella* (1885), and name the major foodborne pathogens and their usual sources.
- Distinguish bacteria, viruses and parasites, and use log reductions to describe how much a step like cooking or handwashing reduces germs.
- Trace cross-contamination with a harmless simulated "germ," and cook chicken fajitas with separate boards and a thermometer.

> **Warm-up.** Think about the last time you or someone you know had an upset stomach after a meal. What do people usually blame? List three things in a kitchen that could actually carry germs from raw meat to a salad.

WATCH

Foodborne Illness: What Problem?

Integrated Food Safety Centers of Excellence · 11:00

https://www.youtube.com/watch?v=2QQvhFPZedM

> **WHEN TO WATCH**
> During session 1. Note the leading causes of foodborne illness named in the video and the steps from farm to table where food can become contaminated.

BACKUP VIDEO

FSA Explains: Listeria

FoodStandardsAgency · 1:53

https://www.youtube.com/watch?v=mOXU7Yuhsds

After the main video. A short, clear explanation of Listeria, including who is most at risk.

KEY TERMS

pathogen

A microorganism that can cause disease.

bacteria

Single-celled living organisms that can multiply in food on their own when conditions are right (for example *Salmonella*, *E. coli* O157:H7, *Listeria*, *Campylobacter*).

virus

A tiny particle of genetic material in a protein coat that multiplies only inside living cells. Viruses do not grow in food but are carried by it, especially from unwashed hands (norovirus, hepatitis A).

parasite

An organism that lives on or in a host, such as *Toxoplasma* or the worm *Trichinella*; cooking and sometimes freezing destroy them.

log reduction

A tenfold reduction in the number of germs. A 5-log reduction leaves 1 in 100,000, killing 99.999%.

cross-contamination

Moving germs from one food or surface to another, as from raw chicken to a cutting board to raw vegetables.

CORE IDEAS

The story. In the 1880s a disease called "hog cholera" was killing pigs across American farms, and the new Bureau of Animal Industry of the U.S. Department of Agriculture was asked to find the cause. Its chief, the veterinarian Daniel Elmer Salmon, and his young assistant Theobald Smith studied sick animals in the laboratory. In 1885 Smith isolated a rod-shaped bacterium from them. It turned out not to be the cause of hog cholera (which is a virus), but the bacterium and its many relatives became famous in their own right: in 1900 they were named *Salmonella*, after Salmon, the head of the laboratory.

How they figured it out. Salmon and Smith used the new methods of Robert Koch's school: grow the microbe in pure culture, then test whether it causes disease. Their search produced one honest wrong guess and one great discovery: *Salmonella* species are now known to be one of the leading bacterial causes of foodborne illness worldwide. The Centers for Disease Control and Prevention estimates that each year

about 48 million Americans get sick from foodborne illness, about 128,000 are hospitalized and about 3,000 die. Norovirus causes the most illnesses; *Salmonella* causes the most hospitalizations and deaths among the bacteria.

The kitchen science. Foodborne pathogens come in three kinds. **Bacteria**, such as *Salmonella* (poultry, eggs, produce), *Campylobacter* (poultry), *E. coli* O157:H7 (undercooked ground beef, raw produce), *Listeria* (deli meats, soft cheeses, which can grow even in the refrigerator), *Clostridium perfringens* (large pots of food left warm) and *Staphylococcus aureus* (from hands; it makes a heat-stable toxin), can multiply in food. **Viruses** such as norovirus cannot grow in food but spread easily from unwashed hands and sick food handlers. **Parasites** are larger organisms found in some meats, fish and water. The cook's defenses work on all three: clean hands and surfaces, separate raw foods, cook to safe temperatures and chill promptly. Each defense reduces germs by a factor we can count in "logs."

Let's cook. You will cook chicken fajitas, a meal that puts raw chicken and fresh vegetables side by side, so the skill is **preventing cross-contamination**: two boards, two sets of tools, clean hands between tasks, and a thermometer in the chicken.

PICTURE STUDY



Daniel Elmer Salmon, Unknown photographer, Late 19th century · Photograph · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Daniel Elmer Salmon (1850–1914) earned the first Doctor of Veterinary Medicine degree awarded in the United States and led the USDA's Bureau of Animal Industry, which fought animal diseases and began federal meat inspection.

Look closely

- Look at his face and clothing. What kind of work do you imagine he did each day?
- Imagine his laboratory: microscopes, culture tubes, sick animals in pens. What would make that work dangerous?
- This photograph is formal and posed. Why do you think scientists of his time were photographed this way?

Talk about it

1. The bacterium named for Salmon was actually found by his assistant, Theobald Smith. Is it fair that it carries Salmon's name? Why are discoveries sometimes named for the head of a laboratory?
2. Why did a department of agriculture study diseases of farm animals, and how does that protect the food you eat?

3. What is one habit you could teach your family that would make *Salmonella* less likely to reach your table?

Safety first. Raw chicken can carry *Salmonella* and *Campylobacter*: use a separate board, knife and plate for it, do not rinse it (that splashes germs), and wash hands for 20 seconds after touching it. Cook chicken to 165 °F (74 °C). Anyone with vomiting or diarrhea should not cook for others until at least 48 hours after symptoms end.

KITCHEN LAB

Following an Invisible Germ

You will coat a “raw chicken” stand-in with a harmless tracer to see how far a cook can spread germs without noticing, then cook a fajita dinner using the safe routine.

You will need

- A raw potato or apple to stand in for raw chicken
- Ground cinnamon or cocoa mixed with a few drops of oil (the “germ” tracer)
- Two cutting boards, two knives and a roll of paper towels
- Soap, a timer and a clean towel
- A large skillet, tongs and an instant-read thermometer
- Your lab notebook

Chicken Fajitas

Serves 4–6 (8–10 fajitas) · Prep 25 min (plus 20 min marinating) · Cook 15 min

Ingredients

- 1½ lb (680 g) boneless, skinless chicken breasts or thighs, cut into thin strips
- Marinade: 2 tablespoons oil, 2 tablespoons lime juice, 1 teaspoon chili powder, 1 teaspoon ground cumin, ½ teaspoon garlic powder, ½ teaspoon paprika, 1 teaspoon salt
- 1 tablespoon oil for the vegetables
- 2 bell peppers (different colors) and 1 large onion, sliced
- 8–10 flour or corn tortillas, warmed
- Toppings: salsa, sliced avocado or guacamole, shredded lettuce, sour cream or plain yogurt, lime wedges

Method

1. **Vegetables first:** on the clean “produce” board, slice the peppers, onion and toppings and set them aside.

2. **Then the chicken:** on the "raw meat" board, slice the chicken and toss it with the marinade in a bowl. Refrigerate 20 minutes. Wash the knife, board and your hands with hot soapy water.
3. Heat the skillet over medium-high heat with 1 tablespoon oil. Cook the peppers and onion 5–6 minutes until softened and charred in spots; move them to a plate.
4. Lift the chicken from the marinade with tongs (discard the marinade) and cook in one layer, in batches if needed, 5–7 minutes, until it reaches 165 °F (74 °C).
5. Return the vegetables, toss, and serve with warm tortillas and toppings on a clean plate (never the plate that held raw chicken).
6. Wash both boards and the tongs, then sanitize them and the counter. Refrigerate leftovers within 2 hours.

Allergy check: Contains wheat (flour tortillas) and milk (sour cream or cheese if used). For wheat-free, use corn tortillas. Check the salsa label.

Steps

1. **Prediction.** List every surface you think the tracer will reach.
2. **Careless round.** Rub the tracer on the potato ("raw chicken"). Cut it on a board, then, without washing, slice a cucumber or bread on the same board, open the refrigerator, turn on the faucet and pick up a spoon. Then look carefully (use a flashlight) and record everywhere the tracer appears.
3. **Clean up** fully with soap and water.
4. **Careful round.** Repeat using two boards, washing hands for 20 seconds after handling the "chicken," and using a paper towel to turn off the faucet. Record where tracer appears now.
5. **Compare** the two rounds in a table.
6. **Cook** the fajitas using the careful routine, and record the chicken's final temperature.
7. **Conclusion.** Which habits stopped the tracer? Which surprised you? Write a three-rule poster for your kitchen.
8. Sanitize the counter and boards.

Tips

- Cut ready-to-eat foods before raw meat, so the board for produce is never at risk.
- Wash hands with soap and running water for at least 20 seconds, scrubbing backs of hands, between fingers and under nails.
- Color-code your boards (for example, red for raw meat, green for produce).

Check your work

- ☐ I can name the major foodborne pathogens and distinguish bacteria, viruses and parasites.
- ☐ I can use log reductions to describe how much a safety step reduces germs.
- ☐ I prevented cross-contamination while cooking chicken to 165 °F.

LAB NOTEBOOK

1. Make a table of six foodborne pathogens: type, common food sources, and the main defense against each.
2. Draw a kitchen map and mark where the tracer spread in the careless and careful rounds.
3. Record the fajita recipe and the chicken's temperature.

KEY FORMULAS

$$N_{\text{after}} = \frac{N_{\text{before}}}{10^{\,\text{log reduction}}}$$

$$\text{percent killed} = \left(1 - 10^{-\text{log reduction}}\right) \times 100\%$$

From history. Theobald Smith went on to discover, with Frederick Kilborne, that Texas cattle fever was spread by ticks (1893), the first proof that an arthropod could carry a disease. Daniel Salmon helped begin federal meat inspection in the United States.

WORKED EXAMPLES

Example 1. A cutting board has 1,000,000 (10^6) bacteria after raw chicken. Washing with soap and hot water gives about a 3-log reduction; sanitizing gives about 2 more logs. How many remain after each step?

Show solution

1. After washing: $\frac{10^6}{10^3} = 10^3 = 1000$.
2. After sanitizing: $\frac{10^3}{10^2} = 10^1 = 10$.

Answer: 1,000 after washing and about 10 after sanitizing: a 5-log reduction overall.

Example 2. What percentage of bacteria does a 5-log reduction kill?

Show solution

1. $\left(1 - 10^{-5}\right) \times 100\% = (1 - 0.00001) \times 100\% = 99.999\%$.

Answer: 99.999%. Food scientists say “five nines.”

Example 3. The CDC estimates 48 million foodborne illnesses a year in the United States. With a population of about 330 million, about what fraction of people is that, and how many in a town of 20,000?

Show solution

1. $\frac{48 \times 10^6}{330 \times 10^6} = 0.145$, about 1 in 7.
2. $0.145 \times 20{,}000 = 2900$.

Answer: About 1 person in 7 each year; about 2,900 people in a town of 20,000.

Example 4. A sick food handler's hand carries about 10^5 norovirus particles, and as few as about 18 particles may cause illness. If a 20-second wash with soap removes about 99%, how many remain, and is that safe?

Show solution

1. 99% removed is a 2-log reduction: $\frac{10^5}{10^2} = 10^3 = 1000$.

Answer: About 1,000 particles, still far more than enough to make someone sick. This is why people with vomiting or diarrhea must not prepare food for others, even after washing.

PRACTICE

1. Easy Which causes the most foodborne illnesses in the United States, according to the CDC?

   Show answer

   Norovirus.

2. Easy Why should raw chicken not be rinsed in the sink?

   Show answer

   Rinsing splashes bacteria onto the sink, counters and nearby food; cooking, not rinsing, kills them.

3. Easy What is a 3-log reduction as a percentage?

   Show answer

   99.9%.

4. Medium 10^7 bacteria undergo a 4-log reduction. How many remain?

   Show answer

   $10^3 = 1000$

5. Medium Why can viruses be spread by food even though they cannot grow in food?

   Show answer

   They survive on food and surfaces and need only a few particles to infect; a sick handler can transfer them.

6. **Medium** Which pathogen can grow at refrigerator temperatures and is a special risk in deli meats and soft cheeses?

   Show answer

   Listeria monocytogenes.

7. **Medium** Who isolated the bacterium later named *Salmonella*, and in what year?

   Show answer

   Theobald Smith, working in Daniel Salmon's USDA laboratory, in 1885.

8. **Medium** Why must a person with vomiting or diarrhea not cook for others?

   Show answer

   They shed huge numbers of germs, such as norovirus; washing cannot reduce them to a safe level.

9. **Hard** A board starts with 2×10^6 bacteria. After washing, 2×10^3 remain. What log reduction is that?

   Show answer

   $\log_{10}(1000) = 3$-log.

10. **Hard** Using CDC estimates, about what fraction of foodborne illnesses lead to hospitalization?

    Show answer

    $128{,}000 / 48{,}000{,}000 \approx 0.27\%$, about 1 in 375.

11. **Challenge** *Staphylococcus aureus* toxin is not destroyed by normal cooking. Explain why that makes temperature control before cooking, not just cooking, important.

    Show answer

    If the bacteria multiply in food left warm, they produce toxin that survives reheating, so the food can sicken people even after the bacteria are killed; food must be kept out of the danger zone from the start.

COMMON MISTAKES

- Putting cooked food back on the plate that held it raw.
- Using the marinade from raw meat as a sauce without boiling it.
- A quick rinse of the hands instead of a 20-second wash with soap.

- Believing that if food smells fine it is safe; most pathogens do not change smell or taste.

> **Make it a game · Wanted Posters.** Draw a wanted poster for each of four pathogens: Salmonella, E. coli O157:H7, a norovirus and a parasite. List the usual food source and the control step, but not the name. Your parent guesses the pathogen from each poster. Tell how Salmon and Smith isolated the bacterium in 1885.

7.2 Growth Curves and FAT TOM: Fanny Hesse's Agar

OBJECTIVES

- Tell how Fanny Hesse suggested agar from her kitchen as a solid medium for growing bacteria in Robert Koch's circle (1881).
- Describe the phases of a bacterial growth curve and the six FAT TOM conditions, and calculate growth with $N = N_0 \cdot 2^{t/g}$.
- Grow microbes from kitchen surfaces on sealed potato slices (never opened), and prepare a chicken salad kept out of the danger zone.

> **Warm-up.** If one bacterium divides into two every 20 minutes, how many are there after 1 hour? After 4 hours? Make a guess for 8 hours before you calculate it.

WATCH

What Is FAT TOM? Food Safety Factors Explained

Food Safety Training School · 4:26

https://www.youtube.com/watch?v=fdLeMQ0HqbM

> **WHEN TO WATCH**
> During session 1. Write down the six letters of FAT TOM and what each stands for, with one example for each.

BACKUP VIDEO

phases of bacterial growth, lag, log or exponential, stationary, and death phase.

Scientist Cindy · 3:12

https://www.youtube.com/watch?v=CfOecDMBrOk

Before the worked examples. An animated walk through the lag, log, stationary and death phases of a growth curve.

KEY TERMS

agar
A gelling substance from red seaweed that stays solid at body temperature; used to grow bacteria on plates.

binary fission
A bacterium dividing into two identical cells.

generation time

The time for a population of bacteria to double; as short as about 20 minutes for some pathogens in ideal conditions.

growth curve

The pattern of growth over time: lag (adjusting), log or exponential (doubling), stationary (resources run low) and death phases.

FAT TOM

The six conditions bacteria need: Food, Acidity, Temperature, Time, Oxygen, Moisture.

danger zone

40–140 °F (4–60 °C), the temperature range in which bacteria grow fastest. (The FDA Food Code for restaurants uses 41–135 °F.)

CORE IDEAS

The story. In the early 1880s Robert Koch's laboratory in Berlin was racing to grow disease-causing bacteria in pure cultures, but its solid medium, gelatin, melted at warm temperatures and was digested by many bacteria. Walther Hesse, a physician working with Koch's methods, faced the same problem. His wife, Fanny Angelina Hesse, who helped in his laboratory as an illustrator and technician, suggested agar, which she used in her kitchen to make jellies and puddings hold their shape in summer heat; she had learned of it from a Dutch neighbor who had lived in Java. In 1881 Walther tried it, it worked, and Koch adopted it. Julius Petri, another of Koch's assistants, designed his shallow covered dish in 1887. Agar plates are still used in every microbiology laboratory.

How they figured it out. A solid surface lets each bacterium grow into its own visible pile, a colony, so different microbes can be separated, counted and studied. Agar was perfect: it melts near the boiling point, sets around 90–100 °F (32–40 °C), stays solid at body temperature, and almost no bacteria can digest it. A kitchen ingredient made modern microbiology possible.

The kitchen science. Bacteria reproduce by **binary fission**. When conditions are good, a population moves through a **lag phase** (adjusting), a **log phase** (doubling every generation, sometimes as fast as about every 20 minutes), a **stationary phase** (food runs out and wastes build up) and a **death phase**. A cook's job is to keep food in the lag phase or to stop growth entirely by denying one of the six FAT TOM conditions: **F**ood (protein-rich, moist foods are most hazardous), **A**cidity (most pathogens grow poorly below pH 4.6), **T**emperature (fastest in the danger zone, 40–

140 °F), **T**ime (the 2-hour rule, 1 hour above 90 °F), **O**xygen (some need it, some grow without it) and **M**oisture (measured as water activity; most pathogens need a_w above about 0.85). Exponential growth is why time matters so much: a few bacteria are harmless, but a few doublings too many turns them into millions.

Let's cook. You will make a chicken salad, a dish that is handled after cooking and served cold, so the skill is **keeping cold food cold**: cooling the cooked chicken quickly, mixing with chilled ingredients, and serving within the time limits.

PICTURE STUDY



Bacterial Colonies, Drawn by Fanny Hesse, Fanny Angelina Hesse, 1880s · Ink drawing (scientific illustration) · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Before laboratories had cameras on their microscopes, scientists depended on skilled illustrators. Fanny Hesse drew the colonies her husband grew, and her suggestion of agar made those colonies possible to grow at all.

Look closely

- Look at the different colonies in each strip. How do their sizes and colors differ?
- How could a scientist use these shapes to tell one kind of bacterium from another?
- Look at the fine dots and lines. How long do you think a drawing like this took?

Talk about it

1. Fanny Hesse's idea came from her own kitchen. What other kitchen knowledge might be useful in a laboratory?
2. Each colony began as a single cell. Using doubling, about how many generations does it take one cell to make a colony of a billion (about 2^{30})?

3. Why does a cook want to prevent exactly what a microbiologist wants to grow?

Safety first. The potato plates are sealed in zip-top bags and **never opened** after sealing: bacteria and molds from surfaces can include pathogens. Observe them through the bag, then throw them away sealed. Keep the chicken salad at or below 40 °F and discard it if it sits out more than 2 hours (1 hour above 90 °F).

KITCHEN LAB

Kitchen Culture Plates (Sealed)

Which kitchen surfaces carry the most microbes, and does washing make a difference? You will make simple culture plates from cooked potato slices, touch them to surfaces, seal them, and watch colonies grow without ever opening the bags.

You will need

- A potato, a knife and a small pot
- Six zip-top sandwich bags and a marker
- Clean cotton swabs
- A warm, dark place (about 75–85 °F)
- Cooked chicken (for the recipe), a bowl and a thermometer
- Your lab notebook

Classic Chicken Salad

Serves 6 (sandwiches or lettuce cups) · Cook 20 min · Chill 1 hr · Assemble 10 min

Ingredients

- 1½ lb (680 g) boneless, skinless chicken breasts (or 3 cups cooked chicken)
- ½ cup (115 g) mayonnaise (store-bought, made with pasteurized eggs) or half mayonnaise and half plain Greek yogurt
- 1 tablespoon lemon juice and 1 teaspoon Dijon mustard
- 2 celery ribs, diced; 1 cup red grapes, halved; 2 green onions, sliced
- ½ teaspoon salt and ¼ teaspoon pepper
- Optional: ⅓ cup chopped toasted pecans or almonds
- Bread, croissants or lettuce leaves for serving

Method

1. Put the chicken in a saucepan, cover with cold water by 1 inch, add a pinch of salt, and bring to a simmer. Cover, lower the heat and poach gently 12–15 minutes, until 165 °F (74 °C) in the thickest part.

2. Lift out the chicken and spread it on a clean plate to cool for 10 minutes, then refrigerate it, uncovered, until cold (40 °F or below), about 30–45 minutes.
3. Chop the cold chicken. In a bowl, mix the mayonnaise, lemon juice, mustard, salt and pepper; fold in the chicken, celery, grapes, onions and nuts.
4. Serve right away or refrigerate up to 3 days. At a picnic, keep it in a cooler with ice, out of the sun.
5. Wash the saucepan and the board used for raw chicken in hot soapy water.

Allergy check: Contains eggs (mayonnaise) and milk (if using yogurt); tree nuts if you add pecans or almonds; wheat if served on bread. Dijon mustard can cause reactions in some people.

Steps

1. **Make plates.** Peel the potato, cut six slices ¼ inch thick, and boil them 5 minutes (to kill microbes already on them). Lift each with clean tongs straight into its own bag and let cool slightly with the bag open but held closed over the top.
2. **Inoculate.** Leave one bag untouched (control). For the others, rub a clean swab on a surface and touch it gently across the potato: kitchen counter, sink handle, phone, unwashed fingertip, washed fingertip. Seal each bag immediately and label it.
3. **Incubate** the sealed bags in a warm, dark place. **Never open them again.**
4. **Observe** through the bag every day for 3–5 days. Count colonies and describe their colors and shapes; sketch them.
5. **Hypothesis check.** Before you look on day 1, rank which plates you expect to grow most.
6. **Make** the chicken salad, recording the chicken's temperature when cooked and when chilled.
7. **Conclusion.** Compare the washed and unwashed finger plates and the control. Explain why the control matters.
8. **Dispose** of the sealed bags in the trash without opening them. Wash your hands.

Tips

- Fuzzy growth is mold; shiny, smooth, round spots are usually bacterial colonies.
- If the control plate grows too, your slices or tongs were not sterile; that is useful data about technique.
- Spread hot cooked chicken out on a plate to cool faster before refrigerating.

Check your work

- ☐ I can describe the phases of bacterial growth and the six FAT TOM conditions.
- ☐ I can calculate growth with N = No · 2
- t/g and find the time to reach a given number.
- ☐ I cultured surface microbes safely in sealed bags and kept a cold salad out of the danger zone.

LAB NOTEBOOK

1. Draw and label a bacterial growth curve on a log scale with all four phases.
2. Make a FAT TOM chart with one way a cook controls each factor.
3. Sketch your colonies day by day and record the counts.

KEY FORMULAS

$$N = N_0 \cdot 2^{t/g}$$

$$\text{number of generations} = \frac{t}{g} \qquad t = g \cdot \log_2\left(\frac{N}{N_0}\right)$$

From history. Agar comes from red seaweeds and has been used in East Asian cooking for centuries; in Japan it is called *kanten*. Fanny Hesse never sought any credit or payment for her idea, and for many years her role was nearly forgotten.

WORKED EXAMPLES

Example 1. A dish starts with 100 bacteria that double every 20 minutes. How many are there after 4 hours?

Show solution

1. Generations: $\dfrac{240\text{ min}}{20\text{ min}} = 12$.
2. $N = 100 \cdot 2^{12} = 100 \cdot 4096 = 409{,}600$.

Answer: About 410,000 bacteria.

Example 2. How long until those 100 bacteria reach 1,000,000 (often enough to make someone sick for some pathogens)?

Show solution

1. $\dfrac{N}{N_0} = 10^4$; $\log_2(10^4) = \dfrac{4}{\log_{10} 2} = \dfrac{4}{0.301} = 13.3$ generations.
2. $t = 13.3 \times 20\text{ min} = 266\text{ min} \approx 4.4\text{ h}$.

Answer: About 4½ hours in ideal conditions, which is why perishable food left out more than 2 hours is unsafe.

Example 3. In the refrigerator at 38 °F, the same bacteria might double only every 12 hours (and many do not grow at all). How many are there after 2 days?

Show solution

1. $\dfrac{48\text{ h}}{12\text{ h}} = 4$ generations; $N = 100 \cdot 2^4 = 1600$.

Answer: About 1,600, compared with millions in a warm kitchen. Cold does not kill most bacteria, but it slows them dramatically.

Example 4. A picnic lasts from noon to 3 p.m. at 92 °F. Under the USDA rule, how long can the chicken salad stay out of the cooler?

Show solution

1. Above 90 °F the limit is 1 hour, not 2.

Answer: 1 hour. After that it must go back on ice or be thrown away.

PRACTICE

1. Easy What does FAT TOM stand for?

Show answer

Food, Acidity, Temperature, Time, Oxygen, Moisture.

2. Easy What is the danger zone in °F and °C?

Show answer

40–140 °F (4–60 °C).

3. Easy Who suggested agar for growing bacteria, and where had she used it?

Show answer

Fanny Hesse; in her kitchen, to set jellies and puddings.

4. Medium 50 bacteria double every 30 minutes. How many after 3 hours?

Show answer

$50 \cdot 2^{6} = 3200$

5. Medium Why did agar work better than gelatin for growing bacteria?

Show answer

Agar stays solid at body temperature and very few bacteria can digest it; gelatin melts when warm and is digested by many bacteria.

6. Medium Name the four phases of a growth curve in order.

Show answer

Lag, log (exponential), stationary, death.

7. Medium How many generations does it take to go from 1 bacterium to about 1,000,000?

Show answer

$\log_2(10^6) \approx 20$

8. Medium Which FAT TOM factor does each control: (a) refrigerating, (b) adding vinegar, (c) drying, (d) the 2-hour rule?

Show answer

(a) Temperature; (b) Acidity; (c) Moisture; (d) Time.

9. Hard At a generation time of 20 minutes, how long does it take 10 bacteria to reach 10^5?

   Show answer

   $\log_2(10^4) = 13.3$ generations; 266 min $\approx$ 4.4 h.

10. Hard Why does exponential growth make the difference between 2 hours and 4 hours on the counter so important?

    Show answer

    Each 20 minutes doubles the count; 2 extra hours is 6 more doublings, multiplying the bacteria by 64.

11. Challenge A cook says, “It was only out for 3 hours, but I reheated it to 165 °F, so it’s fine.” Explain what is wrong.

    Show answer

    Some bacteria (such as *Staphylococcus aureus* and *Bacillus cereus*) produce toxins while multiplying that are not destroyed by reheating, and spores may survive; food held in the danger zone too long should be discarded.

COMMON MISTAKES

- Opening a culture bag to look closer.
- Thinking refrigeration kills bacteria; it mostly slows them.
- Leaving a mayonnaise-based salad out for a whole party.
- Putting a deep, hot container of food straight into the refrigerator (see Lesson 7.5).

> **Make it a game · Double and Count.** Start with one bean to represent a bacterium. Double the pile every twenty minutes for four hours, the generation time, and record the count each step. Compare 4 hours in the danger zone and in the refrigerator. Then recite FAT TOM and the phases of a growth curve. Explain Fanny Hesse's agar.

7.3 Outbreak Detectives: John Snow to E. coli O157:H7

OBJECTIVES

- Tell how John Snow traced the 1854 Broad Street cholera outbreak to a water pump, and how investigators traced the 1993 E. coli O157:H7 outbreak to undercooked hamburgers.
- Calculate attack rates and relative risk from an outbreak table.
- Show that burger color does not tell you when ground beef is safe, and cook burgers to 160 °F.

> **Warm-up.** Twenty people ate at a church supper and eight became sick the next day. What questions would you ask to find out which food made them sick? Write at least five.

WATCH

[Ep1] John Snow and Cholera — What's the Connection?

Let's Learn Public Health · 2:08

https://www.youtube.com/watch?v=D2DzDDyKjR4

> **WHEN TO WATCH**
> During session 1. As you watch, list the steps Snow followed, from noticing the cases to recommending action. The video is short; you will use those steps all lesson.

KEY TERMS

outbreak

Two or more cases of the same illness linked to a common source.

epidemiology

The study of how diseases are distributed in populations and what causes them.

attack rate

The percentage of people exposed to a possible source who became ill.

relative risk

The attack rate among the exposed divided by the attack rate among the unexposed. Much greater than 1 points to the source.

E. coli O157:H7

A strain of *E. coli* that makes Shiga toxin and can cause bloody diarrhea and kidney failure (hemolytic uremic syndrome), especially in children.

adulterant

A substance that makes food unlawful to sell. In 1994 the USDA declared E. coli O157:H7 an adulterant in raw ground beef.

CORE IDEAS

The story. In late August 1854 cholera struck the Soho neighborhood of London, and within days hundreds of people had died. The physician John Snow suspected that cholera spread through contaminated water, not through "bad air," as most experts believed. In January 1993, on the other side of the world and a century and a half later, children in Washington State began arriving at hospitals with bloody diarrhea, and some developed kidney failure. More than 700 people in four states became ill and four children died.

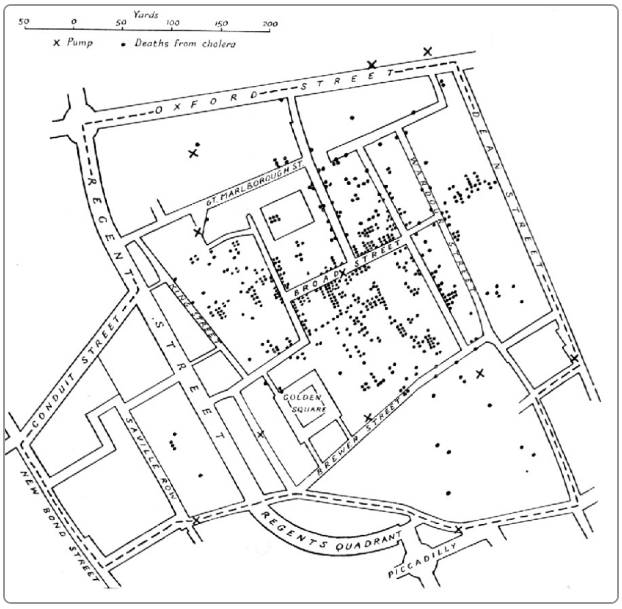
How they figured it out. Snow went door to door, recorded the home of every death, and plotted them on a map. They clustered around the public pump on Broad Street. He also found exceptions that proved the rule: workers at a nearby business that had its own well, and did not use the pump, were spared, while a woman who lived far away but had water from Broad Street brought to her died. He persuaded the local officials to remove the pump handle, and later showed that the pump's well was contaminated by a nearby cesspool. In 1993, Washington health investigators interviewed sick children and compared them with healthy ones; nearly all the sick had eaten hamburgers at the same restaurant chain. Laboratory testing matched the bacteria in patients to the bacteria in undercooked patties. The patties had not reached a temperature high enough to kill E. coli O157:H7. The outbreak led to stricter cooking rules, and in 1994 the USDA declared the bacterium an adulterant in raw ground beef.

The kitchen science. Outbreak detectives use the same reasoning Snow did: find the cases, ask what they share, compare them with people who did not get sick, test the suspected source, and act. The key numbers are the **attack rate** (what fraction of people who ate a food got sick) and the **relative risk** (how much more likely eaters were to get sick than non-eaters). For ground beef, the science is about where bacteria live: on a whole steak, bacteria are only on the surface, which searing kills, so whole cuts are safe at 145 °F. Grinding mixes surface bacteria all through the meat, so ground beef must be cooked to 160 °F (71 °C) all the way through. Color is

not a reliable guide: the USDA reports that about one in four hamburgers turns brown in the middle before it reaches a safe temperature, and some stay pink after they are safe.

Let's cook. You will cook hamburgers and record the color and temperature of each, to see for yourself why the thermometer, not your eyes, decides when they are done.

PICTURE STUDY



Map of Cholera Deaths around Broad Street, John Snow, 1854 (published 1855) · Printed map · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Snow's map is one of the most famous diagrams in the history of science. Each black mark records deaths at that address; the pumps are marked with crosses.

Look closely

- Find Broad Street and its pump. Where are the marks thickest?
- Find streets near the edges of the map. Are there fewer deaths there?
- Find other pumps on the map. Are there clusters around them too?
- Look for blocks with few or no deaths close to the pump. What might explain them?

Talk about it

1. A map shows where cases occurred, not why. What other evidence did Snow need?
2. How is a modern outbreak investigation of hamburgers like Snow's investigation of water?
3. Why do you think so many experts resisted Snow's idea, and what finally convinced people?

> **Safety first.** Use a separate board and plate for raw ground beef and wash hands after shaping patties. Cook ground beef to 160 °F (71 °C) measured in the center of each patty, inserting the thermometer from the side. Children, older adults, pregnant women and people with weak immune systems should never eat undercooked ground beef.

KITCHEN LAB

Color Lies, Thermometers Don’t

Can you tell when a hamburger is safe by its color? You will cook patties, cut a test patty at several temperatures, and compare the inside color with the thermometer reading.

You will need

- A heavy skillet or grill pan (or an outdoor grill with an adult)
- An instant-read thermometer and a timer
- A raw-meat board, a spatula and a clean plate
- A knife for cutting test patties
- Your lab notebook and a camera or colored pencils

Skillet Hamburgers

Serves 6 · Prep 10 min · Cook 10–12 min

Ingredients

- 2 lb (900 g) ground beef (80–85% lean)
- 1½ teaspoons salt and ½ teaspoon pepper
- 1 teaspoon Worcestershire sauce (optional)
- 6 hamburger buns, toasted
- Toppings: lettuce, tomato, onion, pickles, cheese slices, ketchup and mustard

Method

1. Gently mix the beef with the salt, pepper and Worcestershire sauce. Shape 6 patties ¾ inch thick, pressing a shallow dimple in the center of each (it keeps them flat as they cook). Wash your hands.
2. Heat the skillet over medium-high heat. Cook the patties 4–5 minutes per side.
3. Check each patty from the side with the thermometer: it must read 160 °F (71 °C) in the center. Add cheese in the last minute if you like.

4. Put cooked patties on a clean plate, never the one that held them raw. Serve on toasted buns with toppings.
5. Wash the raw-meat board, spatula and plate in hot soapy water and sanitize them. Refrigerate leftovers within 2 hours.

Allergy check: Contains wheat (buns) and milk (if adding cheese); Worcestershire sauce often contains fish (anchovy). Use gluten-free buns or lettuce wraps for wheat-free.

Steps

1. **Hypothesis.** Predict the temperature at which the center of a patty turns from pink to brown.
2. **Test patties.** Make three extra small patties. Cook them and remove one at about 140 °F, one at 150 °F and one at 160 °F. Cut each in half immediately and photograph or color the inside. (The 140 °F and 150 °F test patties are not safe to eat; return them to the pan until they reach 160 °F, or discard them.)
3. **Data.** For every patty you cook, record the final temperature and the inside color (red, pink, light pink, tan, brown).
4. **Analyze.** Was there any patty that looked done before 160 °F, or pink after it?
5. **Outbreak problem.** Work the attack-rate problems in the worked examples and practice set.
6. **Conclusion.** Explain why ground beef needs a higher temperature than steak, and why color is not a safe test.
7. Clean and sanitize everything that touched raw beef.

Tips

- Leaner ground beef can brown early; meat that was frozen and thawed often browns before it is safe.
- Do not press patties with the spatula while cooking; it squeezes out juice.
- Let the thermometer settle for a few seconds and check more than one patty.

Check your work

- ☐ I can tell how Snow and the 1993 investigators found the source of an outbreak.
- ☐ I can calculate attack rates and relative risk.
- ☐ I cooked burgers to 160 °F and showed that color is not a reliable test.

LAB NOTEBOOK

1. Draw a simple outbreak map for an imaginary event and mark where the cases cluster.
2. Make a table of your patties: temperature and inside color.
3. Write the five steps of an outbreak investigation in your own words.

KEY FORMULAS

$$\text{attack rate} = \frac{\text{ill}}{\text{ill} + \text{well}} \times 100\%$$

$$\text{relative risk} = \frac{\text{attack rate (ate the food)}}{\text{attack rate (did not eat it)}}$$

From history. Snow's later "Grand Experiment" compared London homes supplied by two water companies, one drawing water from the Thames downstream of sewage outlets and one upstream; cholera deaths were many times higher in the first. Today the John Snow Society honors him, and the site of the pump is marked on Broadwick Street.

WORKED EXAMPLES

Example 1. At a church supper, 30 people ate the chicken salad and 18 became ill; 20 did not eat it and 2 became ill. Find both attack rates and the relative risk.

Show solution

1. Ate: $\frac{18}{30} \times 100\% = 60\%$. Did not eat: $\frac{2}{20} \times 100\% = 10\%$.
2. Relative risk: $\frac{60\%}{10\%} = 6.0$.

Answer: Eaters were six times as likely to become ill; the chicken salad is the prime suspect.

Example 2. At the same supper, 25 people ate green beans and 10 became ill; 25 did not and 10 became ill. Find the relative risk for the beans.

Show solution

1. $\frac{10}{25} = 40\%$ for both groups; $\frac{40\%}{40\%} = 1.0$.

Answer: A relative risk of 1.0: the beans are not linked to the illness.

Example 3. In Snow's data for one district, households supplied by one water company had about 315 cholera deaths per 10,000 houses and those supplied by another about 37 per 10,000. Find the relative risk.

Show solution

1. $\dfrac{315}{37} = 8.5$.

Answer: About 8.5: houses on the first company's water were roughly eight times as likely to suffer a cholera death. (Snow's 1855 "grand experiment" compared exactly these two companies, one drawing water downstream of London's sewage.)

Example 4. Ground beef must reach 160 °F; a whole steak is safe at 145 °F with a 3-minute rest. Convert both to Celsius and find the difference.

Show solution

1. $\frac{5}{9}(160 - 32) = 71.1$ °C; $\frac{5}{9}(145 - 32) = 62.8$ °C; difference 8.3 °C (15 °F).

Answer: 71 °C and 63 °C; ground meat needs 15 °F more because grinding spreads surface bacteria throughout.

PRACTICE

1. Easy What did John Snow do to stop the Broad Street outbreak?

   Show answer

   He persuaded officials to remove the handle of the Broad Street pump.

2. Easy What safe temperature does ground beef need?

   Show answer

   160 °F (71 °C).

3. Easy Of 40 people who ate potato salad, 12 became ill. Find the attack rate.

   Show answer

   30%.

4. **Medium** In the problem above, 3 of 30 people who did not eat potato salad became ill. Find the relative risk.

Show answer

10% for non-eaters; $30/10 = 3.0$.

5. **Medium** Why must ground beef be cooked hotter than a steak?

Show answer

Grinding mixes surface bacteria throughout the meat, so the center must reach a killing temperature.

6. **Medium** Why is color not a reliable sign that a burger is done?

Show answer

Some patties brown before reaching 160 °F (about one in four, per USDA) and some stay pink after they are safe.

7. **Medium** How did the workers at a nearby business with its own well help Snow's case?

Show answer

They did not use the pump and escaped cholera, supporting the idea that the pump water carried the disease.

8. **Medium** What happened in 1994 as a result of the 1993 outbreak?

Show answer

The USDA declared E. coli O157:H7 an adulterant in raw ground beef.

9. **Hard** At a reunion, 60 ate the turkey (24 ill) and 40 did not (4 ill); 50 ate the rolls (14 ill) and 50 did not (14 ill). Which food is the likely source? Show work.

Show answer

Turkey: 40% vs 10%, RR 4.0. Rolls: 28% vs 28%, RR 1.0. The turkey.

10. **Hard** Why do investigators compare sick people with healthy people instead of only interviewing the sick?

Show answer

Many foods may be eaten by everyone; only a comparison shows which food was eaten much more often by the sick.

11. **Challenge** Suggest why children were the most severely affected in the 1993 outbreak, and what a family can do to protect young children.

Show answer

Children's smaller bodies and developing kidneys are more vulnerable to Shiga toxin. Always cook ground beef to 160 °F with a thermometer, avoid cross-contamination, and wash hands, especially for children.

COMMON MISTAKES

- Judging burgers by color or by cutting into them.
- Using the raw-meat plate for cooked burgers.
- Pressing patties with a spatula.
- Blaming the last meal eaten; many illnesses have incubation times of a day or more.

> **Make it a game · Find the Culprit.** Your parent invents a dinner of twelve guests with a food list. Mark six as ill with beans. Compute each food's attack rate among eaters and non-eaters, then relative risk, and name the likely culprit. Do two outbreaks. Compare with John Snow's pump method and the 1993 hamburger investigation.

7.4 HACCP: Safe Food for Astronauts

OBJECTIVES

- Tell how the Pillsbury Company and NASA developed HACCP in the early 1960s to make space food safe, and how it became the standard of the food industry.
- Name the seven HACCP principles and identify critical control points and critical limits in a recipe.
- Write a HACCP plan for chicken and rice soup and follow it while cooking.

> **Warm-up.** Imagine you are packing food for astronauts who will be in space for two weeks with no doctor. What could go wrong with the food? List every hazard you can think of: germs, crumbs, spoilage, anything.

WATCH

Pillsbury - Space Food

US National Archives · 8:48

https://www.youtube.com/watch?v=7xSLCT7Pe4o

> **WHEN TO WATCH**
> During session 1. Notice how much care goes into each package and how the astronauts prepare and eat the food. The film has no narration; write down what you see.

BACKUP VIDEO

What is HACCP? | Food Safety 101

Safe Food Alliance · 4:09

https://www.youtube.com/watch?v=tu5FLi70rAI

After the story. A plain explanation of what HACCP is and why it is preventive rather than reactive.

KEY TERMS

HACCP

Hazard Analysis and Critical Control Points: a system for preventing food-safety hazards by controlling them at specific steps.

hazard

Something biological, chemical or physical that could make food unsafe.

critical control point (CCP)

A step where control is essential to prevent or eliminate a hazard, such as cooking or cooling.

critical limit

The measurable value that must be met at a CCP, such as 165 °F for poultry.

corrective action

What to do when a critical limit is not met, such as continuing to cook or throwing the food away.

verification and records

Checking that the plan works (calibrating thermometers, reviewing logs) and writing everything down.

CORE IDEAS

The story. When NASA began planning manned spaceflight around 1959, it asked the Pillsbury Company to produce food for astronauts. The challenge was severe: a crumb floating in zero gravity could foul instruments, and a case of food poisoning in orbit could endanger a mission. Pillsbury's food scientist Howard Bauman, working with NASA and the U.S. Army's Natick laboratories, realized that testing finished food could never prove it was safe; you would have to test so much that little would be left to eat.

How they figured it out. Instead of testing the end product, the team analyzed every step of making the food, asked what could go wrong at each step, and put tight controls and records at the steps that mattered most. They borrowed the idea from engineering's "failure mode" analysis. Pillsbury presented the system publicly in 1971, after a recall of its own farina for glass contamination convinced the company to use it everywhere. In the 1990s and 2000s HACCP became required for meat and poultry plants, seafood and juice in the United States, and today it is the foundation of food-safety plans worldwide.

The kitchen science. HACCP has seven principles: (1) conduct a hazard analysis; (2) identify the critical control points; (3) set critical limits for each; (4) monitor each CCP; (5) set corrective actions; (6) verify that the system works; (7) keep records. In a home kitchen the critical control points are usually the same few: receiving and storing food cold (at or below 40 °F), separating raw and ready-to-eat foods, cooking to a safe internal temperature, holding hot food at 140 °F or above (135 °F in restaurant codes), cooling quickly (135 °F to 70 °F within 2 hours, then to 41 °F within 4 more), and reheating leftovers to 165 °F. The power of HACCP is its habit of mind: think ahead, measure, write it down.

Let's cook. You will write a HACCP plan for a big pot of chicken and rice soup, then cook it, monitoring and recording each critical control point. The skill is **thinking like a food-safety manager.**

PICTURE STUDY



Apollo Food, NASA photographer, 1968–1972 · Photograph · NASA, Johnson Space Center, Houston

Image: Wikimedia Commons, public domain

Apollo astronauts ate from pouches like these on their way to and from the Moon. Each one was made, tested and packed under a HACCP-style plan that began with Pillsbury and NASA.

Look closely

- Find the bite-sized cubes. Why might they be coated so they would not crumble?
- Find a pouch with a valve. How would astronauts add water?
- Read any labels you can. What information is on each package?
- Look at the packaging materials. What hazards are they protecting against?

Talk about it

1. Why would a crumb be a hazard in a spacecraft?
2. Name two critical control points in making a freeze-dried pouch of beef stew.
3. How does a family kitchen benefit from a system first designed for the Moon?

> **Safety first.** Chicken must reach 165 °F (74 °C); keep the finished soup at 140 °F or above if it will be served over time; cool leftovers quickly in shallow containers (see Lesson 7.5) and reheat to 165 °F. Lift the hot pot with two hands and mitts; ladle, do not pour, hot soup.

KITCHEN LAB

A HACCP Plan for Soup

You will write a full HACCP plan for chicken and rice soup, with a hazard analysis, critical control points, limits, monitoring, corrective actions, verification and a log, and then follow it.

You will need

- A large pot (6–8 qt) with a lid
- A calibrated instant-read thermometer (calibrate today and record it)
- A refrigerator thermometer
- Shallow containers for cooling leftovers
- A clipboard or notebook page set up as a HACCP log
- Your lab notebook

Chicken and Rice Soup

Serves 8 (about 3 quarts) · Prep 20 min · Cook 45 min

Ingredients

- 2 tablespoons olive oil
- 1 onion, 3 carrots and 3 celery ribs, diced
- 3 cloves garlic, minced
- 1½ lb (680 g) boneless, skinless chicken thighs or breasts
- 8 cups (1.9 L) chicken broth
- 1 teaspoon dried thyme, 1 bay leaf, 1 teaspoon salt, ½ teaspoon pepper
- ¾ cup (150 g) long-grain white rice
- 2 cups chopped spinach or kale, 2 tablespoons lemon juice, ¼ cup chopped parsley

Method

1. Heat the oil in the pot over medium heat. Cook the onion, carrots and celery 6–8 minutes, add the garlic for 1 minute.

2. Add the broth, thyme, bay leaf, salt and pepper and bring to a boil. Add the whole chicken pieces, lower to a simmer, cover and cook 15–20 minutes, until the chicken reaches 165 °F (74 °C). (CCP: record the temperature.)
3. Lift out the chicken onto a clean board, shred it with two forks, and set it aside.
4. Add the rice to the simmering soup and cook 15–18 minutes until tender.
5. Return the chicken, add the greens and simmer 2 minutes. Stir in the lemon juice and parsley. Remove the bay leaf.
6. Serve hot. Keep any soup that will be served later at or above 140 °F. Cool leftovers in shallow containers (CCP) and refrigerate. Wash the raw-chicken plate and tongs.

Allergy check: Contains celery (not a U.S. major allergen, but a common allergen elsewhere). Check your broth label for allergens such as wheat or soy.

Steps

1. **Flow chart.** Draw every step of the recipe as boxes from shopping to leftovers.
2. **Hazard analysis.** For each step list biological, chemical and physical hazards (for example, *Salmonella* on raw chicken, cleaning chemicals, a bone fragment, *Bacillus cereus* in cooked rice).
3. **CCPs and limits.** Mark the critical control points and write a measurable critical limit for each.
4. **Monitoring and corrective actions.** For each CCP, write how you will measure it, how often, and what you will do if it fails.
5. **Verify.** Calibrate your thermometer and record the refrigerator temperature.
6. **Cook** the soup, recording each CCP in your log with the time and your initials.
7. **Review.** After the meal, review your log. Did every CCP pass? What would you change in the plan?
8. Clean up and sanitize.

Tips

- A HACCP log should have columns for time, CCP, reading, limit met (yes/no), corrective action and initials.
- Most home kitchens have only four or five true CCPs; do not mark every step critical.
- Rice left warm is a special hazard because *Bacillus cereus* spores survive cooking; cool leftovers of rice soup quickly.

Check your work

- ☐ I can tell how HACCP was developed for space food.
- ☐ I can name the seven HACCP principles and identify CCPs and critical limits.
- ☐ I wrote and followed a HACCP plan for a real recipe.

LAB NOTEBOOK

1. Draw the flow chart of your soup with CCPs circled in red.
2. Paste or copy your completed HACCP log.
3. Write one paragraph on how HACCP thinking could help in another part of life (for example, getting ready for a trip).

KEY FORMULAS

$$\text{cooling rate} = \frac{\Delta T}{\Delta t}$$

$$\text{required average rate (stage 1)} = \frac{135 - 70\ ^\circ\text{F}}{120\ \text{min}} = 0.54\ ^\circ\text{F/min}$$

From history. Space food has changed a great deal: Mercury astronauts squeezed purées from tubes, while astronauts on the International Space Station eat thermostabilized and freeze-dried foods, fresh fruit delivered by supply ships, and even lettuce grown on board.

WORKED EXAMPLES

Example 1. A pot of soup is at 180 °F when the stove is turned off. It must reach 135 °F, then 70 °F within 2 hours of passing 135 °F. If it cools from 135 °F to 98 °F in the first hour, is it on track?

Show solution

1. Needed: $135 - 70 = 65$ °F in 120 min. Achieved: 37 °F in 60 min.
2. Remaining: $98 - 70 = 28$ °F in 60 min. Cooling usually slows as the food nears room temperature.

Answer: Probably on track, but it must be checked; if it is not at 70 °F at the 2-hour mark, the corrective action is to reheat to 165 °F and start cooling again, or discard it.

Example 2. Write the critical limit for each of these CCPs in °F and °C: cooking chicken; hot holding; cold holding; reheating leftovers.

Show solution

1. Cooking chicken: 165 °F (74 °C). Hot holding: 140 °F (60 °C) or above (135 °F in the FDA Food Code). Cold holding: 40 °F (4 °C) or below. Reheating: 165 °F (74 °C).

Answer: 165 °F, 140 °F, 40 °F and 165 °F.

Example 3. A HACCP log shows chicken temperatures of 162, 167, 159 and 170 °F for four batches. Which batches fail, and what is the corrective action?

Show solution

1. Critical limit 165 °F: 162 °F and 159 °F fail.

Answer: Batches 1 and 3 fail; the corrective action is to continue cooking until they reach 165 °F and record the new reading.

Example 4. A space-food scientist wants to be 95% sure that no more than 1 package in 1,000 is contaminated by testing finished packages. Roughly, if each test destroys a package and you would need to test about 3,000 packages, what does this tell you about end-product testing?

Show solution

1. Testing thousands of packages destroys much of the food and still cannot prove every remaining package is safe.

Answer: End-product testing alone is impractical; controlling the process (HACCP) is the answer Pillsbury and NASA reached.

PRACTICE

1. Easy What does HACCP stand for?

   Show answer

   Hazard Analysis and Critical Control Points.

2. Easy Which company developed HACCP with NASA?

   Show answer

   Pillsbury (with NASA and the U.S. Army Natick laboratories).

3. Easy Name the three kinds of food-safety hazards.

   Show answer

   Biological, chemical and physical.

4. Medium List the seven HACCP principles.

   Show answer

   Hazard analysis; identify CCPs; set critical limits; monitor; corrective actions; verification; record keeping.

5. Medium Why did the Pillsbury team decide that testing finished food was not enough?

   Show answer

   You would have to destroy nearly all the food to test it, and testing could still miss contamination; controlling each step prevents hazards instead.

6. Medium Give the critical limits for cold holding and for reheating leftovers.

Show answer

40 °F or below; 165 °F.

7. Medium Is washing produce a critical control point in a soup that will be boiled? Explain.

Show answer

Usually not; the boiling step (cooking) controls biological hazards. Washing still removes dirt (a physical hazard) and is good practice.

8. Medium A refrigerator log reads 38, 39, 44 and 39 °F on four days. What should be done about day 3?

Show answer

Investigate (door left open? overloaded?), check foods, adjust the thermostat, and record the corrective action.

9. Hard Soup cools from 135 °F to 88 °F in 2 hours. Did it meet the first cooling limit? What is the corrective action?

Show answer

No; it needed to reach 70 °F within 2 hours. Reheat to 165 °F and cool again using shallow containers or an ice bath, or discard.

10. Hard Name a chemical hazard and a physical hazard in a home kitchen and a control for each.

Show answer

Chemical: cleaning spray near food, store chemicals away and label them. Physical: glass from a broken jar, sweep and discard any exposed food.

11. Challenge Pillsbury's 1971 presentation followed a recall of farina contaminated with glass. Explain how a HACCP plan could prevent a physical hazard like that.

Show answer

A hazard analysis would identify glass (from light fixtures or containers) as a physical hazard at certain steps; controls could include shatterproof covers on lights, metal or glass detectors, sieving, and inspection logs with corrective actions.

COMMON MISTAKES

- Marking every step as a CCP, which hides the ones that really matter.
- Writing limits that cannot be measured (“cook until done”).
- Not recording readings, so no one can verify the plan worked.
- Leaving a large pot of soup on the stove overnight to cool.

Make it a game · The Inspector Calls. Write numbers one to seven on slips for the HACCP principles. Your parent draws a slip and, as inspector, asks you to apply that principle to a pot of soup: hazard, critical control point, critical limit, monitoring, corrective action, verification or records. Answer in thirty seconds. Tell how Pillsbury and NASA built HACCP.

Scripture. “A prudent man foreseeth the evil, and hideth himself: but the simple pass on, and are punished.” (Proverbs 22:3, KJV)

HACCP is prudence written down: foresee the hazard and prevent it, instead of waiting to see who gets sick.

7.5 The Cold Chain and Safe Leftovers: Frederick McKinley Jones

OBJECTIVES

- Tell how Frederick McKinley Jones invented a practical refrigeration unit for trucks around 1940, helping create the modern cold chain.
- Explain the two-stage cooling rule (135 °F to 70 °F in 2 hours, then to 41 °F in 4 more), and why shallow containers and ice baths cool faster.
- Cool a pot of chili two ways, log the temperatures, and decide which method meets the rule.

> **Warm-up.** Put a refrigerator thermometer in your refrigerator and another in your freezer this morning, and read them now. Are they at or below 40 °F and 0 °F? Where is the warmest spot in your refrigerator?

WATCH

A Flash of Food Safety Active Cooling with a Chill Stick

USDA · 3:19

https://www.youtube.com/watch?v=BNU6Nu0h4Is

> **WHEN TO WATCH**
> During session 1. Copy the two cooling time limits and the methods shown for cooling food quickly.

BACKUP VIDEO

Food Safety - Cooling, Storing and Using Leftovers

Springfield-Greene County Health Department · 2:10

https://www.youtube.com/watch?v=0EErECU8PXU

Before the lab. A county health department shows the ice-bath and shallow-pan methods in a home kitchen.

KEY TERMS

cold chain

The unbroken series of refrigerated storage and transport that keeps perishable food cold from producer to consumer.

surface-area-to-volume ratio

How much surface a food has for each unit of its volume; shallow and small portions have more surface and cool faster.

Newton's law of cooling

The rate of cooling is proportional to the temperature difference between the food and its surroundings.

two-stage cooling

The FDA Food Code rule: cool cooked food from 135 °F to 70 °F within 2 hours, then to 41 °F or below within 4 more hours (6 hours total).

ice bath

A sink or large bowl of ice and water around a container of hot food, which cools it quickly by conduction and convection.

CORE IDEAS

The story. Frederick McKinley Jones was born in Cincinnati in 1893, was orphaned young, and left school by about the sixth grade. He taught himself mechanics and electronics by working in garages and reading everything he could. In the 1930s, working in Minneapolis for the businessman Joseph Numero, he designed a compact, shock-resistant refrigeration unit that could be mounted on a truck. He received a patent for it in 1940, and he and Numero founded the company that became Thermo King. During World War II his portable units kept blood, medicine and food cold for soldiers. He earned more than 60 patents, and in 1991 he became the first African American to receive the National Medal of Technology (awarded after his death).

How they figured it out. Earlier refrigerated rail cars used blocks of ice and salt, which melted, weighed a great deal and needed icing stations along the way. A mechanical refrigerator for a truck had to survive constant bouncing and still be small and light. Jones solved it by rethinking the design for the road, mounting the unit under or in front of the cargo box. His work made it possible to carry fresh and

frozen foods long distances by truck, linking farms, factories, stores and homes in a "cold chain."

The kitchen science. A cooked dish passes through the danger zone twice: once when it is heated and once when it cools. Heating is fast; cooling a big pot is slow, because heat must travel from the center to the surface. The FDA Food Code sets a two-stage rule: from 135 °F to 70 °F within 2 hours (the range where bacteria grow fastest), then from 70 °F to 41 °F within the next 4 hours. A deep stockpot of chili set in the refrigerator can take 12 hours or more to cool in the center, warming the refrigerator as it does. Cooling speeds up when you increase the **surface area** (divide food into shallow containers no more than about 2 inches deep), increase the temperature difference (an ice bath, or an ice wand), and stir (convection). **Newton's law of cooling** says the rate of cooling is proportional to the temperature difference, so food cools fastest at first and slows as it nears the temperature of its surroundings.

Let's cook. You will make a large pot of chili, serve it, and cool the leftovers by two methods while logging temperatures against the two-stage rule. The skill is **cooling safely**.

PICTURE STUDY



The Iceman, Crowley, Louisiana, Russell Lee, for the Farm Security Administration, 1938 · Photograph · Library of Congress, Washington, D.C.

Image: Wikimedia Commons, public domain

Before electric refrigerators were common, many American homes kept food in an icebox, and the iceman delivered blocks of ice several times a week. Frederick McKinley Jones's refrigeration units, and electric home refrigerators, soon replaced this work.

Look closely

- Find the wagon's sign. What did the Home Ice Company sell, and how would the iceman carry a block into a house?
- Look at the wagon. How did the ice stay frozen during the day's route?
- Look at the street and buildings. What season and climate do you think it is?
- What would happen to a family's milk and meat if the iceman did not come?

Talk about it

1. This is one link in a cold chain. Name the other links between a California field and your refrigerator.
2. How did Jones's truck refrigerator change where food could travel?
3. What is the last link of the cold chain, and who is responsible for it?

> **Safety first.** Hot chili splatters and holds heat: ladle it into containers rather than pouring from the big pot. Refrigerate leftovers within 2 hours of cooking; never leave a pot on the stove overnight. Reheat leftovers to 165 °F (74 °C). Keep the refrigerator at or below 40 °F and the freezer at 0 °F.

KITCHEN LAB

Racing the Cooling Clock

Which cooling method meets the two-stage rule? You will cool equal amounts of hot chili in a deep container and in a shallow pan in an ice bath, logging temperatures every 15 minutes.

You will need

- A large pot for chili
- One deep, narrow container (a 2-quart pitcher or deep pot) and one shallow pan (9 × 13-inch)
- A sink or large bowl for an ice bath, and plenty of ice
- Two thermometers if possible (or one, used carefully between containers)
- A timer and graph paper
- Your lab notebook

Family Chili

Serves 8 (about 3 quarts) · Prep 20 min · Cook 1 hr

Ingredients

- 2 lb (900 g) ground beef or ground turkey
- 1 tablespoon oil, 1 large onion and 1 bell pepper (diced), 4 cloves garlic (minced)
- 3 tablespoons chili powder, 2 teaspoons ground cumin, 1 teaspoon dried oregano, 1 teaspoon smoked paprika
- 1½ teaspoons salt and ½ teaspoon pepper
- 2 cans (15 oz each) kidney or pinto beans, drained and rinsed
- 1 can (28 oz) crushed tomatoes and 1 can (15 oz) tomato sauce
- 1 cup (240 mL) beef or chicken broth
- Toppings: shredded cheese, sour cream or yogurt, sliced green onions

Method

1. Heat the oil in the pot over medium-high heat. Brown the meat, breaking it up, until no pink remains and it reaches 160 °F (165 °F for turkey). Spoon off excess fat.
2. Add the onion and pepper and cook 5 minutes; add the garlic and spices and stir 1 minute.
3. Add the beans, tomatoes, tomato sauce, broth, salt and pepper. Bring to a boil, then simmer partly covered for 40 minutes, stirring now and then.
4. Serve hot with toppings.
5. Cool leftovers as in the lab, then refrigerate in covered shallow containers (up to 4 days) or freeze (up to 4 months). Reheat to 165 °F.
6. Wash the pot and the board used for raw meat.

Allergy check: Contains milk if served with cheese or sour cream. Check the broth label. For a meatless chili, replace the meat with 2 more cans of beans and 1 cup of diced zucchini.

Steps

1. **Hypothesis.** Predict how long each container will take to fall from 135 °F to 70 °F.
2. **Divide.** After the meal, put 4 cups of chili (at or above 135 °F) into the deep container and 4 cups into the shallow pan. Set the shallow pan in an ice bath; leave the deep container on the counter at room temperature (for the test only).
3. **Log.** Record the center temperature of each every 15 minutes, stirring the shallow pan gently each time, until it reaches 41 °F (finish its cooling in the refrigerator) or until 2 hours pass for the deep container.
4. **Corrective action.** When the deep container fails the first stage at 2 hours, record it and then discard it (it was in the danger zone too long) or immediately reheat it to 165 °F and cool it properly.
5. **Graph** both cooling curves against time with lines at 135, 70 and 41 °F.
6. **Fit.** Use two points on each curve to estimate k in Newton’s law of cooling.
7. **Conclusion.** Which method met the rule? Explain with surface area, temperature difference and stirring.
8. Clean up; store the safely cooled chili.

Tips

- Freeze water in clean plastic bottles to use as homemade ice wands to stir into a pot of soup or chili.
- Leave containers uncovered (or loosely covered) on the top shelf of the refrigerator until cold, then cover them.
- Do not stack hot containers; air must flow around them.

Check your work

- ☐ I can describe the cold chain and Frederick McKinley Jones's contribution.
- ☐ I can state and apply the two-stage cooling rule and Newton's law of cooling.
- ☐ I tested two cooling methods and identified the one that meets the rule.

LAB NOTEBOOK

1. Draw the cold chain from field to fork as a chain of links, with a temperature for each link.
2. Graph your two cooling curves with the limit lines.
3. Write a "leftovers rule card" for your refrigerator door.

KEY FORMULAS

$$\frac{dT}{dt} = -k\,(T - T_{\text{env}})$$

$$T(t) = T_{\text{env}} + (T_0 - T_{\text{env}})\,e^{-kt}$$

From history. Jones also invented early devices for movie theaters, including improvements to sound equipment and a ticket-dispensing machine. Today refrigerated trucks, ships and warehouses move fresh food around the world, and food scientists monitor the cold chain with electronic temperature loggers that travel with each shipment.

Example 1. Chili at 135 °F is placed in an ice bath at 35 °F. With k = 0.020 per minute, what is its temperature after 60 minutes, and does it meet the first-stage limit?

Show solution

1. $T = 35 + (135 - 35)e^{-0.020 \times 60} = 35 + 100e^{-1.2}$.
2. $e^{-1.2} = 0.301$; $T = 35 + 30.1 = 65$ °F.

Answer: About 65 °F after 1 hour, well within the 2-hour limit.

Example 2. The same chili left in a deep pot in a 70 °F room has k = 0.0040 per minute. What is its temperature after 2 hours?

Show solution

1. $T = 70 + (135 - 70)e^{-0.0040 \times 120} = 70 + 65e^{-0.48} = 70 + 65(0.619) = 110$ °F.

Answer: About 110 °F after 2 hours, still in the danger zone and far from 70 °F. It fails.

Example 3. A 6-quart pot of chili 8 inches deep is divided into 4 shallow pans, each 2 inches deep. By about how much does this shorten the distance heat must travel from the center?

Show solution

1. Deep pot: heat travels about 4 inches from the center to the top or bottom (and similar to the sides).
2. Shallow pans: about 1 inch from the middle to the top or bottom.

Answer: About 4 times shorter. Because conduction time grows with the square of distance, the center can cool roughly 16 times faster.

Example 4. Convert the two-stage cooling temperatures to Celsius: 135 °F, 70 °F and 41 °F.

Show solution

1. $\frac{5}{9}(135-32) = 57\ ^\circ\text{C}$; $\frac{5}{9}(70-32) = 21\ ^\circ\text{C}$; $\frac{5}{9}(41-32) = 5\ ^\circ\text{C}$.

Answer: 57 °C, 21 °C and 5 °C.

PRACTICE

1. Easy State the two-stage cooling rule.

   Show answer

   135 °F to 70 °F within 2 hours, then to 41 °F within 4 more hours.

2. Easy How deep should containers be for cooling leftovers?

   Show answer

   About 2 inches or less.

3. Easy In what year did Jones patent his truck refrigeration unit?

   Show answer

   1940.

4. Medium Why does a large pot of chili cool so slowly in the refrigerator?

   Show answer

   Heat must conduct from the deep center to the surface, the volume is large compared with its surface, and the refrigerator air is a poor conductor.

5. Medium Food at 120 °F in a 40 °F refrigerator has k = 0.010 per minute. Find its temperature after 60 minutes.

   Show answer

   $40 + 80e^{-0.6} = 40 + 43.9 = 84\ ^\circ\text{F}$

6. Medium Name three ways to speed cooling.

   Show answer

   Shallow containers, an ice bath, ice wands, stirring, cutting large foods into smaller pieces.

7. Medium What temperature must leftovers reach when reheated?

Show answer

165 °F (74 °C).

8. Medium Why was ice-cooled rail transport difficult compared with Jones's units?

Show answer

Ice was heavy, melted, needed icing stations, and gave uneven cooling.

9. Hard Chili cools from 135 °F to 95 °F in 30 minutes in an ice bath at 35 °F. Find k.

Show answer

$60 = 100e^{-30k} \Rightarrow k = \ln(100/60)/30 = 0.017$ per min

10. Hard With the k from problem 9, how long to reach 70 °F?

Show answer

$35 = 100e^{-0.017t} \Rightarrow t = \ln(100/35)/0.017 = 62$ min

11. Challenge Explain why splitting a pot into four shallow pans can make the center cool roughly 16 times faster, not just 4 times.

Show answer

Conduction time grows with the square of the distance heat must travel; cutting the depth by 4 cuts the time by about $4^2 = 16$.

COMMON MISTAKES

- Leaving a pot on the stove to cool overnight.
- Putting a deep, covered pot of hot food in the refrigerator.
- Reheating leftovers only until warm, not to 165 °F.
- Overloading the refrigerator so cold air cannot circulate.

> **Make it a game · Cooling Race.** Put equal amounts of hot tap water in a shallow dish and a tall cup. Predict which hits 70 degrees Fahrenheit first, then read the thermometer every two minutes and record. Explain with surface area to volume and Newton's law of cooling. Add the two-stage rule. Tell how Frederick Jones built the cold chain.

UNIT 7

Microbes II: Food Safety

The same microscopic world that raises bread and sours cabbage also contains pathogens: bacteria, viruses and parasites that can cause serious illness. This unit is about keeping them out of food: what they are, how they grow, how outbreaks are traced, and the systems and habits that prevent them, from handwashing and thermometers to HACCP and the cold chain.

The stories follow Daniel Salmon and Theobald Smith's bacillus, Fanny Hesse's kitchen agar, John Snow's map and the 1993 hamburger outbreak, the Pillsbury and NASA scientists who invented HACCP for astronauts, and Frederick McKinley Jones's truck refrigerator. The labs trace a simulated germ, grow sealed cultures from kitchen surfaces, compare burger color with temperature, write and follow a HACCP plan, and race two cooling methods against the clock. The recipes are chicken fajitas, chicken salad, hamburgers, chicken and rice soup and a big pot of chili.

PREREQUISITES

- Unit 1: thermometer calibration, safe temperatures, lab safety
- Unit 6: microbes, fermentation and pH
- Exponents and logarithms (powers of 2 and 10), taught as needed

MASTERY CHECKLIST

- ☐ I can name the major foodborne pathogens and distinguish bacteria, viruses and parasites.
- ☐ I can describe bacterial growth, apply FAT TOM, and calculate growth with $N = N_0 \cdot 2^{t/g}$.
- ☐ I can calculate attack rates and relative risk and explain how outbreaks are traced.
- ☐ I can explain HACCP's seven principles and write a HACCP plan.
- ☐ I can apply the two-stage cooling rule and Newton's law of cooling.
- ☐ I prevented cross-contamination and cooked and cooled foods to safe temperatures.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **Partnership for Food Safety Education: Fight BAC!**: Free. Printable Clean, Separate, Cook, Chill materials for posting in your kitchen.
- **FDA: Food Code**: Free on the FDA website. The model code for restaurants, including the cooling rules and HACCP guidance used in Lessons 7.4–7.5.
- **A state food-handler course**: Optional. Many states offer an online food-handler card for a small fee; this unit covers much of what the test asks.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

7.1 Bacteria, Viruses and Parasites: Salmon and Smith's Bacillus
3 sessions of 50–90 minutes

7.2 Growth Curves and FAT TOM: Fanny Hesse's Agar
3 sessions of 50–90 minutes (plus 3–5 days of observation)

7.3 Outbreak Detectives: John Snow to E. coli O157:H7 3 sessions of 50–90 minutes

7.4 HACCP: Safe Food for Astronauts 3 sessions of 50–90 minutes

7.5 The Cold Chain and Safe Leftovers: Frederick McKinley Jones
3 sessions of 50–90 minutes

Unit 7 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   Name one bacterium, one virus and one parasite that can be carried by food, with a typical source for each.

2. **5 pts**

   A cutting board has 3×10^6 bacteria. After a 4-log reduction, how many remain? What percentage were killed?

3. **6 pts**

   Explain why washing hands cannot make it safe for a person with norovirus to cook for others.

4. **6 pts**

   What did Fanny Hesse contribute to microbiology, and why did it work?

5. **7 pts**

   200 bacteria double every 20 minutes. How many after 3 hours? How long to reach 2×10^6?

6. **6 pts**

   Name the six FAT TOM factors and one way a cook controls each.

7. **7 pts**

   At a picnic, 45 ate the egg salad (27 ill) and 35 did not (4 ill). Find both attack rates and the relative risk. Is egg salad the likely source?

8. **6 pts**

   Describe how John Snow showed that the Broad Street pump spread cholera.

9. **6 pts**

   Why must ground beef be cooked to 160 °F while a whole steak is safe at 145 °F with a rest? Why can’t you judge doneness by color?

10. **5 pts**

    Why did the Pillsbury team design HACCP instead of testing finished space food?

11. **7 pts**

    List the seven HACCP principles.

12. **6 pts**

    A HACCP log shows cooked chicken at 158 °F and a refrigerator at 45 °F. Give the corrective action for each.

13. **7 pts**

    Chili at 135 °F is in an ice bath at 35 °F with k = 0.015 per minute. Find its temperature at 2 hours. Does it meet the first-stage rule?

14. **5 pts**

    What did Frederick McKinley Jones invent, and why did it matter?

15. **15 pts**

    Short essay (6–8 sentences): Plan a safe church potluck for 50 people. Explain how you would control pathogens at each stage (shopping, preparing, cooking, serving, leftovers) using FAT TOM, safe temperatures, cross-contamination rules and the cooling rule.

ANSWER KEY

1. Bacterium: *Salmonella* (poultry, eggs). Virus: norovirus (sick food handlers). Parasite: *Toxoplasma* or *Trichinella* (undercooked meat). Other correct answers accepted.
2. 300; 99.99%.
3. They shed enormous numbers of virus particles and only a few are needed to infect; a 2-log reduction from washing still leaves far more than an infectious dose.
4. She suggested agar as a solid culture medium; it stays solid at body temperature and few bacteria digest it.
5. $200 \cdot 2^9 = 102{,}400$; $\log_2(10^4) = 13.3$ generations, about 4.4 h.
6. Food (choose and handle high-risk foods carefully), Acidity (vinegar, pH below 4.6), Temperature (keep out of 40–140 °F), Time (2-hour rule), Oxygen (vacuum packing; note some bacteria need none), Moisture (drying, salt, sugar).
7. 60% and 11.4%; RR 5.3. Yes, very likely.
8. He mapped deaths, found them clustered near the pump, studied exceptions (nearby workers with their own well, a distant woman who drank the pump's water), and had the handle removed; the well was found to be contaminated by a cesspool.
9. Grinding spreads surface bacteria throughout; color is unreliable because some burgers brown before reaching 160 °F and some stay pink after.
10. Testing would destroy most of the food and still could not prove every package safe; controlling each step prevents hazards.
11. Hazard analysis; critical control points; critical limits; monitoring; corrective actions; verification; records.
12. Keep cooking to 165 °F and re-check; check the refrigerator (door, thermostat), move or evaluate foods that warmed, and record actions.
13. $35 + 100e^{-1.8} = 35 + 16.5 = 51.5$ °F; yes, below 70 °F.
14. A practical refrigeration unit for trucks (patented 1940); it made long-distance refrigerated transport possible and helped build the cold chain.
15. Answers vary. Full credit for: cold foods kept at or below 40 °F and hot at or above 140 °F; separate boards and hand washing; thermometers and correct temperatures (165, 160, 145 °F); the 2-hour (1-hour above 90 °F) rule while

serving; shallow containers and the two-stage cooling rule for leftovers; reheating to 165 °F; sick people not cooking.

UNIT PROJECT: OUR FAMILY FOOD-SAFETY PLAN

Write a HACCP-style food-safety plan for your own kitchen: a one-page hazard analysis of how food flows through your home (shopping, storage, preparation, cooking, serving, leftovers), the critical control points and limits for each, and a week-long log of refrigerator and freezer temperatures and of every meat and leftover temperature you check.

Then audit one family meal from shopping to leftovers against your plan, correct any problems you find, and make a laminated (or plastic-sleeved) card for the refrigerator door with the safe temperatures and cooling rules. Present your plan to your family at a meal.

LOOK FOR	WHAT IT MEANS
Hazard analysis	Covers biological, chemical and physical hazards at each step of your kitchen's food flow.
CCPs and limits	A few true CCPs with correct, measurable limits and corrective actions.
Records	A complete, honest week-long temperature log.
Audit and corrections	Real problems found and fixed, with notes.
Communication	A clear, accurate refrigerator card and a plan your family can follow.

UNIT 8

Preservation

For most of history, food that was not preserved was soon lost. This unit studies the five great ways people keep food: drying, salting and sugaring, acid, heat, and cold. Each works by attacking the conditions microbes need: water activity, acidity, temperature and time. You will learn the science behind each method and the rules that make home preservation safe.

The stories follow W. J. Scott's discovery of water activity, the salt fishermen of the Grand Banks, Émile van Ermengem's investigation at Ellezelles, Nathan Straus's pasteurized-milk stations and Clarence Birdseye's frozen fish. The labs measure moisture loss, osmosis, the pH of foods, jam's seals and the drip loss of frozen beans. The recipes are apple chips, brined pork tenderloin, refrigerator pickles, strawberry jam processed with a parent, and freezer breakfast burritos.

PREREQUISITES

- Unit 2: latent heat, boiling point and altitude
- Unit 6: pH, lactic fermentation and vinegar
- Unit 7: pathogens, FAT TOM and log reductions

MASTERY CHECKLIST

- ☐ I can explain water activity and calculate moisture content and water removed.
- ☐ I can explain osmosis and how salt and sugar preserve, and make a brine by mass percent.
- ☐ I can explain botulism, spores and the pH 4.6 line, and why low-acid foods need pressure canning.
- ☐ I can explain pasteurization, sterilization, D-values and the 12D process, and adjust canning time for altitude.
- ☐ I can explain fast and slow freezing, blanching and freezer burn, and calculate the energy to freeze food.
- ☐ I preserved food safely by drying, brining, pickling, canning with a parent and freezing.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **National Center for Home Food Preservation**: Free. The University of Georgia's tested recipes and guides for canning, pickling, freezing and drying. Use only tested recipes for canning.
- **A boiling-water canner with a rack and a jar lifter**: Needed only for Lesson 8.4. A large, deep stockpot with a rack or a folded towel in the bottom can work if the water covers the jars by 1–2 inches.
- **A mandoline slicer with a hand guard**: Optional, for even apple slices in Lesson 8.1. Use only with the guard and a parent present.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

8.1 Drying and Water Activity: W. J. Scott's Discovery

3 sessions of 50–90 minutes (plus 2–3 hours of drying)

8.2 Salt, Sugar and Osmosis: The Salt of the Earth

3 sessions of 50–90 minutes (plus 1–8 hours of brining)

8.3 Acid and pH 4.6: Van Ermengem and the Botulism Line

3 sessions of 50–90 minutes

8.4 Canning and Pasteurization: Nathan Straus's Milk Stations

3 sessions of 60–90 minutes

8.5 Freezing and Ice Crystals: Clarence Birdseye

3 sessions of 50–90 minutes (plus freezing time)

Unit 8 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**

   Define water activity and give the approximate a_w below which most bacteria, most molds, and all microbes stop growing.

2. **7 pts**

   500 g of pears at 84% water are dried to 18% moisture. Find the final mass and the water removed.

3. **6 pts**

   Explain how salting preserves fish, using osmosis and water activity.

4. **6 pts**

   How much salt makes a 6% brine with 1,500 g of water?

5. **5 pts**

   A slice goes from 9.0 g to 8.1 g in a solution. Find the percent change and say whether the solution was hypertonic or hypotonic.

6. **6 pts**

   What did van Ermengem discover in 1895, and what clue showed the organism grew without air?

7. **7 pts**

   Explain why pH 4.6 divides boiling-water canning from pressure canning.

8. **5 pts**

   Mix 3 cups of 5% vinegar with 1 cup of water. Find the acid percentage.

9. **7 pts**

   With $D_{121} = 0.21$ min, find the time for a 12D process. If a can starts with 100 spores, how many survive on average?

10. **6 pts**

    Why did Nathan Straus's pasteurized-milk stations save lives?

11. **5 pts**

    A jam recipe says 10 minutes for half-pints at sea level. Find the time at 5,500 ft and at 7,000 ft.

12. **6 pts**

    Explain why fast freezing gives better texture than slow freezing.

13. **7 pts**

    Find the heat removed in freezing 800 g of water from 15 °C to −18 °C (c_{water} 4.18, c_{ice} 2.1, L_f 334 J/g).

14. **6 pts**

    Why are vegetables blanched before freezing, and why is jam not blanched?

15. **15 pts**

    Short essay (6–8 sentences): Choose a food your family eats and explain how it could be preserved by two different methods from this unit. For each method, explain which FAT TOM factor it controls, what the safety rules are, and what happens to quality.

ANSWER KEY

1. The ratio of water vapor pressure above a food to that above pure water (free water). About 0.91 (most bacteria), 0.80 (most molds), 0.60 (all microbes).
2. Solids 80 g; final $80 / 0.82 = 97.6$ g; water removed 402 g.
3. Salt draws water out of the fish and out of microbes by osmosis, and binds water so the water activity falls below what bacteria need.
4. $m = 0.06(m + 1500) \Rightarrow m = 95.7$ g
5. −10%; hypertonic.
6. He identified the bacterium (now *C. botulinum*) that makes botulinum toxin; it grew deep inside the ham and in his laboratory only when air was excluded.
7. Below pH 4.6, botulinum spores cannot germinate, so the 212 °F boiling bath (which kills other microbes) is enough; above it, spores must be destroyed at about 240 °F in a pressure canner.
8. 3.75%.
9. 2.52 min; $100 \times 10^{-12} = 10^{-10}$.
10. Pasteurization killed disease germs in city milk (such as those of tuberculosis and typhoid), so infants and children drinking it were far less likely to become sick or die.
11. 15 minutes; 20 minutes.
12. Fast freezing forms many small ice crystals that do little damage; slow freezing grows fewer, larger crystals that tear cells, causing drip and mushiness.
13. $50{,}160 + 267{,}200 + 30{,}240 = 347{,}600$ J
14. Blanching inactivates enzymes that would degrade frozen vegetables; jam is cooked and preserved by sugar, acid and heat processing.
15. Answers vary. Full credit for two correctly explained methods (drying, salting/sugaring, acidifying, heat processing, freezing), each linked to the factor it controls (moisture/water activity, acidity, temperature/time), accurate safety rules (tested recipes, pH 4.6, pressure canning for low-acid, 0 °F, blanching), and honest quality effects.

UNIT PROJECT: THE FAMILY PANTRY PLAN

Joseph planned ahead for seven lean years. Plan and carry out a small "preservation season" for your family: preserve at least three foods by three different methods from this unit (for example, dried apple chips, refrigerator pickles and frozen blanched vegetables, or jam processed with a parent). For each, keep a record of the tested recipe used, the safety controls, labels with dates, and any measurements (masses, pH, Brix, times).

Then write a two-page pantry plan: an inventory of your family's preserved foods with storage temperature and use-by dates, the science of how each is preserved, and a rotation plan so nothing is wasted. Serve a family meal that uses at least two of your preserved foods.

LOOK FOR	WHAT IT MEANS
Safety	Tested recipes followed exactly; correct pH, temperatures, altitude adjustments; canning only with a parent.
Records and labels	Complete records with measurements; every container labeled and dated.
Science	Correct explanation of how each method controls microbes and affects quality.
Pantry plan	Clear inventory, storage conditions and rotation plan.
Stewardship	Food used well, little waste, a family meal served with thanks.

8.1 Drying and Water Activity: W. J. Scott's Discovery

OBJECTIVES

- Tell how the Australian microbiologist W. J. Scott showed in the 1950s that microbes respond to water activity, not simply to water content.
- Explain water activity (a_w), the limits at which bacteria, yeasts and molds can grow, and how drying preserves food.
- Oven-dry apple chips, calculate their moisture loss and final moisture content, and compare dried fruits.

> **Warm-up.** Compare a fresh grape and a raisin, or a fresh apple slice and a dried one. Which would spoil first on the counter? Both contain sugar; what is different about the water in them?

WATCH

Moisture Content and Water Activity

DRSJSCHMIDT · 6:56

https://www.youtube.com/watch?v=-LiSankbfSk

> **WHEN TO WATCH**
> During session 1. Copy the definition of water activity and the graph of microbial growth limits against a_w.

KEY TERMS

moisture content

The mass of water in a food as a percentage of its total mass (wet basis).

water activity (a_w)

The ratio of the water vapor pressure above a food to that above pure water at the same temperature; it measures how available the water is, from 0 to 1.0.

bound water

Water held tightly by sugars, salts, proteins and starch, unavailable for microbes or reactions.

case hardening

A dry, hard outer layer that forms when food dries too fast, trapping moisture inside.

dehydration

Removing water from food by heat and moving air, lowering a_w.

CORE IDEAS

The story. People have dried food since ancient times: raisins and figs, salted and dried fish, jerky and pemmican, dried beans and grain. In the Andes, farmers freeze and dry potatoes into *chuño* that keep for years. But no one could say exactly how dry was dry enough. In the 1950s William James Scott, a microbiologist at Australia's national science organization, CSIRO, studied *Staphylococcus aureus* and other spoilage organisms growing in foods of different moisture.

How they figured it out. Scott found that two foods with the same water content could behave very differently: one spoiled and the other did not. What mattered was not how much water the food contained but how much of it was free, which he measured as the food's equilibrium relative humidity, or **water activity**. In papers in 1953 and 1957 he showed that each kind of microbe has a minimum water activity below which it cannot grow. His idea became the basis of modern food preservation and of food-safety rules for dried, salted and sugared foods.

The kitchen science. Pure water has $a_w = 1.00$; fresh meat, fruit and vegetables are about 0.97–0.99. Most harmful bacteria need a_w above about 0.91; *Staphylococcus aureus* can grow down to about 0.86; most molds stop around 0.80 and the toughest around 0.61; below about 0.60 no microbes grow. Dried fruit is about 0.60–0.70, jerky about 0.75–0.85 (so it is also salted), crackers and dry cereal about 0.2–0.3. Drying lowers a_w by removing water; salt and sugar lower it by binding water (Lesson 8.2). Drying also concentrates flavor and sugars. Too much heat too fast seals the surface (**case hardening**), trapping moisture inside; low, steady heat with moving air works best. Light-colored fruits brown when cut because of the enzyme polyphenol oxidase; a dip in lemon juice or ascorbic acid slows it.

Let's cook. You will oven-dry cinnamon apple chips, weighing them before and after to calculate moisture loss. The skill is **slicing thin and even**, so every chip dries at the same rate.

PICTURE STUDY



Raisin Drying Racks in a Vineyard, Fresno, California, Unknown photographer, Early 20th century · Photograph · Library of Congress, Washington, D.C.

Image: Wikimedia Commons, public domain

The hot, dry summers of California's San Joaquin Valley made Fresno the raisin capital of the world. Grapes were laid on wooden trays between the vine rows to dry in the sun for two to three weeks.

Look closely

- Find the trays. Why are the grapes spread out in a single layer?
- Look at the sky and the ground. What weather do raisin growers need?
- Look at the vines. Why dry the grapes right in the vineyard?
- How would workers know when the raisins were dry enough?

Talk about it

1. A grape is about 80% water; a raisin about 15%. Estimate the mass of raisins from 100 kg of grapes (hint: keep the solids constant).
2. What would happen to the drying grapes if it rained?
3. Why do raisins keep for months without refrigeration while grapes spoil in days?

Safety first. Slice apples with a sharp knife or a mandoline only with the hand guard and a parent present; a mandoline is one of the most common causes of kitchen cuts. Dry in a low oven (200 °F), use mitts, and store chips in an airtight jar once completely cool and crisp.

KITCHEN LAB

How Much Water Is in an Apple?

How much of an apple is water, and how dry must a chip be to keep? You will weigh slices before and after drying, test whether a lemon dip prevents browning, and compare your chips with store-bought dried fruit.

You will need

- A digital scale (0.1 g if possible)
- A sharp knife or a mandoline with its hand guard
- Two rimmed baking sheets lined with parchment, and wire racks if you have them
- A bowl of water with 2 tablespoons lemon juice
- An airtight jar
- Your lab notebook

Oven-Dried Cinnamon Apple Chips

Serves About 4 cups of chips (4–6 snacks) · Prep 15 min · Dry 2–3 hr · Cool 30 min

Ingredients

- 3 large crisp apples (such as Honeycrisp or Fuji), about 600 g
- 2 tablespoons lemon juice in 2 cups water
- 1 teaspoon ground cinnamon
- 1 tablespoon sugar (optional)

Method

1. Heat the oven to 200 °F (93 °C) with racks in the upper and lower thirds.
2. Wash the apples. Core them and slice crosswise ⅛ inch thick (2–3 mm), as evenly as you can.
3. Dip the slices in the lemon water for 1 minute (keep a few undipped for the lab), then pat dry.
4. Arrange in one layer on the lined sheets (on racks if you have them). Sprinkle with cinnamon and sugar.

5. Dry 1 hour, flip, then dry 1–2 hours more, until the edges curl and the slices feel dry. They crisp as they cool.
6. Cool completely, then store airtight. If chips go soft, re-dry them for 15 minutes.

Allergy check: Contains none of the major allergens.

Steps

1. **Hypothesis.** Predict the percentage of mass the apples will lose, and whether the lemon dip will prevent browning.
2. **Weigh** 20 slices before drying (record dipped and undipped separately).
3. **Dry** and weigh the same slices every 30 minutes until the mass stops changing much.
4. **Calculate** the percent mass lost and the final moisture content, assuming fresh apple is 85% water.
5. **Graph** mass against time. Describe the shape: does drying slow down?
6. **Compare** the color of dipped and undipped chips, and compare your chips with a store-bought dried fruit by snapping and squeezing.
7. **Conclusion.** Explain why drying preserves food using water activity, and why drying slowed near the end.
8. Clean up; wash the mandoline carefully with a brush, never with fingers.

Tips

- Thinner slices dry faster and crisper; uneven slices give some burnt and some chewy chips.
- Propping the oven door open an inch lets moist air escape, if it is safe to do so in your kitchen.
- Store dried foods airtight: they pull moisture from humid air and go soft.

Check your work

☐ I can explain water activity and the a

w limits for bacteria, yeasts and molds.

☐ I can calculate moisture content and water removed.

☐ I dried apples, tracked their mass and explained the drying curve.

LAB NOTEBOOK

1. Draw a water-activity scale from 0 to 1.0, marking common foods and the growth limits of bacteria, yeasts and molds.
2. Graph the mass of your apple slices against drying time.
3. Photograph or draw dipped and undipped slices side by side.

KEY FORMULAS

$$\text{moisture }\% = \frac{m_{\text{water}}}{m_{\text{food}}} \times 100\%$$

$$a_w = \frac{p}{p_0} = \frac{\text{ERH}}{100}$$

From history. Freeze-drying, which removes water from frozen food by sublimation under vacuum, was developed in the twentieth century and is used for instant coffee, astronaut food and camping meals. The Andean *chuño* is an ancient natural version: potatoes are frozen by night, thawed in the day sun and trampled to squeeze out water.

WORKED EXAMPLES

Example 1. Apple slices weigh 400 g fresh and are 85% water. After drying they weigh 75 g. Find the final moisture content.

Show solution

1. Dry solids: $0.15 \times 400 = 60$ g.
2. Water left: $75 - 60 = 15$ g.
3. Moisture: $\dfrac{15}{75} \times 100\% = 20\%$.

Answer: About 20% moisture, typical of dried fruit (a_w roughly 0.6).

Example 2. What percentage of the apple's original water was removed?

Show solution

1. Original water: $0.85 \times 400 = 340$ g; removed $340 - 15 = 325$ g.
2. $\dfrac{325}{340} \times 100\% = 96\%$.

Answer: About 96% of the water was removed.

Example 3. Raoult's law estimates a_w for a sugar solution as the mole fraction of water. Estimate a_w for 100 g of water with 100 g of sucrose (342.3 g/mol).

Show solution

1. Moles water: $\frac{100}{18.02} = 5.55$; sucrose: $\frac{100}{342.3} = 0.292$.
2. $a_w = \frac{5.55}{5.55 + 0.292} = 0.95$.

Answer: About 0.95 (real syrups are a little lower). Even a very sweet syrup does not stop bacteria; jams need more sugar and acid.

Example 4. A food dehydrator holds 1.2 kg of sliced fruit at 85% water. How much energy is needed just to evaporate the water down to 20% moisture? Use 2,400 J/g for evaporation at drying temperatures.

Show solution

1. Solids: $0.15 \times 1200 = 180$ g; final mass $\frac{180}{0.80} = 225$ g.
2. Water removed: $1200 - 225 = 975$ g.
3. $q = 975 \times 2400 = 2.34 \times 10^6$ J.

Answer: About 2.3 MJ, which is why drying takes hours and why sun-drying, where the climate allows, is so economical.

PRACTICE

1. Easy What is the water activity of pure water?

   Show answer

   1.00.

2. Easy Below about what a_w do most harmful bacteria stop growing?

   Show answer

   About 0.91 (some, like *Staphylococcus aureus*, down to about 0.86).

3. Easy Why does a lemon-juice dip keep cut apples from browning?

   Show answer

   Its acid (and vitamin C) slows the browning enzyme, polyphenol oxidase.

4. Medium What did W. J. Scott show about water and microbial growth?

Show answer

That growth depends on water activity (free water), not total water content; each microbe has a minimum a_w.

5. Medium 200 g of 80%-water mushrooms are dried to 10% moisture. Find the final mass.

Show answer

Solids 40 g; $40/0.90 = 44$ g.

6. Medium A food's air reaches 65% relative humidity in a sealed jar. What is its a_w?

Show answer

0.65.

7. Medium Why can two foods with the same water content have different water activities?

Show answer

In one food more water is bound by sugars, salts, proteins or starch, so less is free.

8. Medium What is case hardening, and how do you prevent it?

Show answer

A dry crust that traps moisture inside; dry at a lower temperature with good air flow.

9. Hard Estimate a_w by Raoult's law for 100 g water with 30 g salt (NaCl, 58.44 g/mol, which gives 2 particles per unit).

Show answer

Water 5.55 mol; ions $2 \times 0.513 = 1.03$; $a_w = 5.55/6.58 = 0.84$.

10. Hard 100 kg of grapes at 80% water become raisins at 15% water. Find the mass of raisins.

Show answer

Solids 20 kg; $20/0.85 = 23.5$ kg.

11. **Challenge** Why does jerky need salt as well as drying, while apple chips need only drying?

Show answer

Jerky is usually dried only to about a_w 0.75–0.85, which some pathogens (such as *S. aureus*) can tolerate; salt lowers a_w further and inhibits them. Meat also carries more pathogens than fruit and must be heated to a safe temperature before or during drying.

COMMON MISTAKES

- Slicing unevenly, so some pieces burn while others stay moist.
- Storing chips warm in a jar, which makes them soggy.
- Using a mandoline without the hand guard.
- Thinking dried food can never spoil; if it absorbs moisture, mold can grow.

> **Make it a game · Water Activity Rank.** Write six foods on cards: fresh chicken, bread, jam, honey, crackers, dried pasta. Rank them from highest to lowest water activity in sixty seconds and say which microbes still grow at each. Your parent reveals the order with your lesson notes. Fewest misplaced cards wins. Tell W. J. Scott's discovery.

8.2 Salt, Sugar and Osmosis: The Salt of the Earth

OBJECTIVES

- Explain how salt and sugar preserve food by osmosis and by lowering water activity, and tell how salting fed fishermen and sailors for centuries.
- Measure the mass change of vegetable slices in salt and sugar solutions, and calculate brine concentrations.
- Brine and roast a pork tenderloin to 145 °F, and explain how brining keeps meat juicy.

> **Warm-up.** Sprinkle salt on a few cucumber slices and leave others plain. After 15 minutes, look at the plate. Where did the water come from? Press both kinds of slices; which are more limp?

WATCH

Osmosis and coleslaw

Harvard Online · 2:26

https://www.youtube.com/watch?v=8o0bS4X756g

> **WHEN TO WATCH**
> During session 1. Watch the cabbage give up its water to salt, then explain in your own words why water moved out of the cells.

BACKUP VIDEO

Osmosis and Water Potential (Updated)

Amoeba Sisters · 9:49

https://www.youtube.com/watch?v=L-osEc07vMs

Before the lab. A thorough, friendly explanation of osmosis, water potential and hypertonic and hypotonic solutions.

KEY TERMS

osmosis

The movement of water through a semipermeable membrane from a region of lower solute concentration to one of higher solute concentration.

hypertonic

A solution with more solute than the cell's contents; cells in it lose water and shrink.

hypotonic

A solution with less solute than the cell's contents; cells in it gain water and swell.

brine

A salt solution used to season, preserve or tenderize food, often 3–6% salt for brining meat.

curing

Preserving food with salt (often with sugar and nitrites), which draws water out of food and microbes.

CORE IDEAS

The story. For centuries salt was one of the most important foods in the world because it made other foods last. From about 1500, fishermen from Portugal, Spain, France and England sailed to the cod-rich Grand Banks off Newfoundland, split and salted their catch, and dried it on wooden racks on the shore. Salt cod kept for months without refrigeration and fed sailors, armies and whole nations. Herring were packed in barrels of salt across northern Europe. Fruit was preserved in sugar as jams, candied peel and fruit pastes.

How they figured it out. Fishermen and cooks knew from long experience how much salt kept fish sound. Scientists explained why only in the nineteenth and twentieth centuries. In 1877 the German botanist Wilhelm Pfeffer measured osmotic pressure through artificial membranes, and the Dutch chemist Jacobus van 't Hoff later showed that it follows a law much like the gas laws (he received the first Nobel Prize in Chemistry in 1901). Food scientists then connected osmosis with water activity (Lesson 8.1): dissolved salt and sugar bind water and pull it out of cells, including the cells of bacteria and molds.

The kitchen science. A cell membrane lets water pass but holds back most dissolved substances. Surround a cell with a solution more concentrated than its contents

(**hypertonic**), and water flows out by **osmosis**: cucumbers go limp, cabbage releases its juice (Lesson 6.4), and bacteria shrivel and stop growing. That is how salting and sugaring preserve. Salt also lowers water activity: a saturated brine (about 26% salt) has a_w about 0.75. Brining meat works a little differently: in a mild brine (about 5%), salt diffuses into the meat, dissolves some muscle proteins (especially myosin) and changes their structure so they hold more water; brined meat can lose less juice when cooked. Sugar in a brine adds flavor and browning.

Let's cook. You will brine a pork tenderloin, then sear and roast it to 145 °F with a 3-minute rest. The skill is **making a brine by mass percent** and timing it, since too long a brine makes meat salty and spongy.

PICTURE STUDY



The Herring Net, Winslow Homer, 1885 · Oil on canvas · Art Institute of Chicago

Image: Wikimedia Commons, public domain

Winslow Homer lived on the coast of Maine and painted the hard, dangerous work of fishermen. Herring caught like this were salted, smoked or pickled to feed people far from the sea.

Look closely

- Find the herring in the net and in the boat. How can you tell how heavy the catch is?
- Look at the waves and the sky. What dangers do the men face?
- Find the ship in the distance. Why would it matter that it stay close?
- Look at the men's clothing. How is it suited to their work?

Talk about it

1. Fresh fish spoil within days. Why were salting and smoking essential to fishermen before refrigeration?
2. How does salt stop bacteria from growing in salted fish?
3. Jesus called many of His first disciples from their fishing boats. What does Homer's painting help you understand about their work?

> **Safety first.** Keep meat in the brine in the refrigerator (at or below 40 °F), in a covered nonreactive container, and discard the brine afterward. Do not brine meat labeled “enhanced” or “injected with solution,” which is already salted. Cook pork to 145 °F (63 °C) with a 3-minute rest.

KITCHEN LAB

Osmosis in the Kitchen

How do salt and sugar solutions change the mass of plant tissue? You will soak identical potato (or cucumber) slices in five solutions and measure the change, then brine and roast a pork tenderloin.

You will need

- A potato (or cucumber) and a knife, a ruler and a scale (0.1 g if possible)
- Five cups or jars and labels
- Salt and sugar
- Paper towels and a timer
- A gallon zip-top bag or covered container, a skillet and a sheet pan
- Your lab notebook

Brined, Pan-Roasted Pork Tenderloin

Serves 4–6 · Brine 1–2 hr · Prep 10 min · Cook 20–25 min

Ingredients

- 2 pork tenderloins, about 1 lb (450 g) each, silver skin trimmed
- **Brine:** 1 L (4¼ cups) cold water, 53 g salt, 2 tablespoons brown sugar
- 1 tablespoon oil and 1 teaspoon black pepper
- Glaze: 2 tablespoons honey, 1 tablespoon Dijon mustard, 1 teaspoon fresh or ½ teaspoon dried thyme

Method

1. Stir the salt and sugar into the water until dissolved. Put the tenderloins in a zip-top bag or covered container, pour in the brine, and refrigerate 1–2 hours (no longer).
2. Heat the oven to 425 °F (220 °C). Remove the pork, rinse briefly, and pat completely dry. Season with pepper. Discard the brine.
3. Heat the oil in an oven-safe skillet over medium-high heat. Sear the tenderloins on all sides, about 6 minutes in all.

4. Brush with the glaze and transfer the skillet to the oven. Roast 10–15 minutes, until the thickest part reads 140–145 °F.
5. Rest 3 minutes (the temperature should reach at least 145 °F / 63 °C), then slice and serve.
6. Wash the board and container that held raw pork; sanitize them.

Allergy check: Contains none of the nine major allergens (Dijon mustard can cause reactions in some people). Honey is never given to babies under one year.

Steps

1. **Prepare solutions** of 200 g each: plain water, 2% salt, 10% salt, 10% sugar and 30% sugar.
2. **Hypothesis.** Predict which slices will gain mass and which will lose it.
3. **Cut** ten slices of equal size (two per solution). Blot and weigh each.
4. **Soak** for 60 minutes, then blot gently and weigh again. Describe each slice's firmness.
5. **Calculate** the average percent mass change for each solution and graph it against concentration. Estimate where the line crosses zero: the concentration that matches the potato's cells.
6. **Brine and cook** the pork. (Optional: roast one piece unbrined, weigh both raw and cooked, and compare their cooking losses.)
7. **Conclusion.** Explain your results with osmosis and connect them to salting fish and brining meat.
8. Clean up; wash all containers and sanitize the raw-meat surfaces.

Tips

- Kosher salt flakes are larger than table salt: a tablespoon weighs less, so always weigh salt for brines.
- Tenderloin is lean and small; brine it only 1–2 hours. A whole chicken might brine 4–8 hours.
- Pat brined meat very dry before searing, or it will steam instead of browning.

Check your work

☐ I can explain osmosis and how salt and sugar preserve food.

- ☐ I measured mass changes in five solutions and found the isotonic point.
- ☐ I brined and roasted pork to a safe temperature.

LAB NOTEBOOK

1. Draw a plant cell in hypotonic, isotonic and hypertonic solutions, with arrows for water movement.
2. Graph percent mass change against concentration for salt and for sugar.
3. Write the brine recipe as mass percentages and scale it to 3 L.

KEY FORMULAS

$$\text{salt }\% = \frac{m_{\text{salt}}}{m_{\text{salt}} + m_{\text{water}}} \times 100\%$$

$$\text{mass change }\% = \frac{m_{\text{after}} - m_{\text{before}}}{m_{\text{before}}} \times 100\%$$

From history. Salt has shaped history: Roman soldiers received salt allowances (the source of the word "salary," according to an old tradition), and salt taxes were important to many governments. Salt is mentioned many times in Scripture as a sign of covenant faithfulness and preservation.

WORKED EXAMPLES

Example 1. How much salt makes a 5% brine with 1,000 g (1 L) of water?

Show solution

1. $\dfrac{m}{m + 1000} = 0.05 \;\Rightarrow\; m = 0.05m + 50 \;\Rightarrow\; 0.95m = 50 \;\Rightarrow\; m = 52.6\text{ g}.$

Answer: About 53 g of salt (roughly 3 tablespoons of table salt, or more of a coarser kosher salt, which is why weighing is better).

Example 2. A potato slice weighs 8.40 g before and 7.14 g after an hour in 10% salt solution. Find the percent mass change and say whether the solution was hypertonic or hypotonic to the potato.

Show solution

1. $\dfrac{7.14 - 8.40}{8.40} \times 100\% = -15\%.$

Answer: −15%: the slice lost water, so the solution was hypertonic.

Example 3. A slice in plain water goes from 8.20 g to 8.69 g. Find the percent change and explain.

Show solution

1. $\dfrac{0.49}{8.20} \times 100\% = +6.0\%$.

Answer: +6.0%: plain water is hypotonic to the potato's cells, so water moved in and the slice became firmer.

Example 4. Van 't Hoff's law gives osmotic pressure π = iMRT. Estimate π for a 0.86 mol/L salt solution (about 5%) at 25 °C (298 K), with i = 2 and R = 0.0821 L·atm/(mol·K).

Show solution

1. $\pi = (2)(0.86)(0.0821)(298) = 42$ atm.

Answer: About 42 atmospheres, an enormous pull on water, which explains how strongly salt draws water out of cells.

PRACTICE

1. Easy In osmosis, which way does water move?

   Show answer

   From lower solute concentration to higher solute concentration, across a membrane.

2. Easy Find the salt percentage of 30 g of salt in 570 g of water.

   Show answer

   5%.

3. Easy Why do salted cucumber slices go limp?

   Show answer

   Salt makes a hypertonic solution on the surface; water leaves the cells by osmosis.

4. Medium How much salt for 2,000 g of water to make a 6% brine?

   Show answer

   $m = 0.06(m + 2000) \Rightarrow m = 127.7$ g

5. **Medium** A slice changes from 6.50 g to 5.85 g. Find the percent change.

Show answer

-10%.

6. **Medium** Why does salt cod keep for months without refrigeration?

Show answer

Heavy salting and drying lower water activity so far that bacteria and most molds cannot grow.

7. **Medium** Why does brined meat often stay juicier?

Show answer

Salt diffuses in and changes muscle proteins so they hold more water, so less juice is lost during cooking.

8. **Medium** Why should you not brine a pork chop labeled “enhanced with a solution”?

Show answer

It has already been injected with salt solution; brining again makes it too salty.

9. **Hard** Potato slices gain 4% in 1% salt and lose 6% in 4% salt. Estimate (by straight-line interpolation) the salt concentration with no change.

Show answer

Zero lies 4/10 of the way from 1% to 4%: $1 + 0.4 \times 3 = 2.2\%$.

10. **Hard** Use π = iMRT to estimate the osmotic pressure of a 1.0 mol/L sucrose solution (i = 1) at 298 K.

Show answer

$(1)(1.0)(0.0821)(298) = 24.5 \text{ atm}$

11. **Challenge** Explain why jam (about 65% sugar) keeps on the shelf after opening for a while but spoils faster than honey, which is about 80% sugar.

Show answer

Higher sugar means lower water activity; honey (a_w about 0.5–0.6) is too dry for almost all microbes, while jam (about 0.80–0.85) can eventually grow molds and yeasts once opened.

COMMON MISTAKES

- Measuring salt by volume, so the brine is much stronger or weaker than intended.
- Brining too long, making the meat salty and spongy.
- Leaving meat in brine at room temperature.
- Reusing a brine that held raw meat.

> **Make it a game · Osmosis Bet.** Salt one cucumber slice and leave another plain. Predict the mass change in grams for each after fifteen minutes, write your guess, then weigh. Calculate percent change and name which solution was hypertonic. Your parent also guesses; closest guess wins. Explain how salting preserved fish for sailors.

> **Scripture.** “Ye are the salt of the earth: but if the salt have lost his savour, wherewith shall it be salted?” (Matthew 5:13, KJV)
>
> Salt in the ancient world seasoned and preserved food. Jesus called His followers to be like salt: giving flavor and keeping what is good from decay.

8.3 Acid and pH 4.6: Van Ermengem and the Botulism Line

OBJECTIVES

- Tell how Émile van Ermengem identified the botulism bacterium after an outbreak at Ellezelles, Belgium, in 1895.
- Explain why *Clostridium botulinum* is dangerous in sealed, low-acid foods, why pH 4.6 is the dividing line, and why low-acid foods need pressure canning.
- Measure the pH of foods and make quick refrigerator dill pickles.

> **Warm-up.** Line up foods from your kitchen (a tomato, a cucumber, canned green beans, pickles, lemon juice, milk, a banana). Guess which are below pH 4.6 (acidic) and which are above. You will test them in the lab.

WATCH

Botulism Survivor Urges Safe Canning

Utah State University Extension · 10:29

https://www.youtube.com/watch?v=ON8FEyVHE30

> **WHEN TO WATCH**
> During session 1. A woman who survived botulism from home-canned food tells what happened and what she learned. Note the canning mistakes she describes and the rules she urges.

Note: A serious personal account of illness; told calmly and without graphic detail.

BACKUP VIDEO

Program 10 -- Preventing Botulism in Home Canning

K-State Extension · 2:22

https://www.youtube.com/watch?v=eIXQ7EegEpY

After the main video. An extension specialist explains which foods are high-acid and low-acid and why low-acid foods need a pressure canner.

KEY TERMS

botulism

A rare, severe paralytic illness caused by a toxin made by *Clostridium botulinum*.

anaerobic

Living without oxygen. *C. botulinum* grows in sealed jars and cans, inside low-acid foods, where there is no oxygen.

acidified food

A low-acid food (such as cucumbers) made safe by adding enough acid to bring its pH to 4.6 or below.

spore

A tough, dormant form of some bacteria that survives boiling and can germinate later when conditions allow.

pH 4.6

The acidity below which *C. botulinum* spores cannot germinate and make toxin. High-acid foods are below it; low-acid foods are above.

CORE IDEAS

The story. In December 1895, at the village of Ellezelles in Belgium, a group of musicians who had played at a funeral shared a meal that included raw, salted and smoked ham. Over the following days 34 of them fell ill with blurred vision, difficulty swallowing and weakness, and three died. Émile van Ermengem, professor of bacteriology at the University of Ghent, investigated. He found a rod-shaped bacterium in the ham and in the body of one victim, grew it only in the absence of oxygen, and showed that it made a toxin that caused the same paralysis in laboratory animals. He named it *Bacillus botulinus*, from the Latin *botulus*, "sausage," because the illness had long been linked to sausages.

How they figured it out. Van Ermengem combined careful case histories with laboratory work. He noticed that the illness came from a single food, that the ham had been kept in brine without enough salt near its bottom, and that the organism would grow only where air was excluded, as it was deep in the ham. His findings explained a century of mysterious "sausage poisonings" and became the basis of all canning safety.

The kitchen science. *Clostridium botulinum* forms **spores** found in soil and on vegetables. Spores survive boiling. In a sealed jar or can of a moist, **low-acid** food

(vegetables, beans, meat, soups), with no oxygen and at room temperature, spores can germinate and produce botulinum toxin, one of the most powerful poisons known. But they cannot grow if the food is acidic enough: at **pH 4.6 or below**. That line divides canning into two worlds. High-acid foods (most fruits, jams, properly acidified pickles and tomatoes with added acid) can be safely canned in a boiling-water bath at 212 °F, which kills molds, yeasts and bacteria but not spores; the acid keeps any spores from growing. Low-acid foods must be pressure canned at about 240 °F (116 °C), which destroys spores, using a tested recipe. Pickling acidifies cucumbers with vinegar so that their pH falls well below 4.6.

Let's cook. You will make quick refrigerator dill pickles in a vinegar brine and check their pH. Refrigerator pickles are not canned; they are kept cold and eaten within a few weeks. The skill is **using a tested acid ratio**, never weakening the vinegar.

PICTURE STUDY



Émile van Ermengem, Unknown photographer, Late 19th century · Lithograph · Ghent University, Belgium

Image: Wikimedia Commons, public domain

Émile van Ermengem (1851–1932) studied in Robert Koch's laboratory in Berlin and became professor at Ghent. His investigation at Ellezelles is a model of how laboratory science and careful questioning work together.

Look closely

- Look at his face and clothing. What qualities would a bacteriologist of his time need?
- Imagine his laboratory at Ghent. What tools would he use to grow bacteria without oxygen?
- This is a formal portrait. What does it tell you about how scientists were regarded in his time?

Talk about it

1. Van Ermengem noticed the bacterium grew only without air. How did that clue explain why it grew deep in the ham?
2. Why do you think botulism had been linked to sausages for a century before anyone knew the cause?
3. How do his findings protect families who can food at home today?

Safety first. Refrigerator pickles must stay refrigerated and be eaten within about a month. Never reduce the vinegar or use vinegar weaker than 5%. Never home-can low-acid foods (vegetables, beans, meat, soups) except with a pressure canner, a tested USDA/NCHFP recipe and an adult. Never taste food from a bulging, leaking or foul-smelling jar or can; throw it away without opening, in a sealed bag.

KITCHEN LAB

Which Side of 4.6?

You will measure the pH of a range of foods with test strips, sort them into high-acid and low-acid, and make refrigerator dill pickles, testing their pH over a week.

You will need

- pH test strips (range about 2–9)
- Small cups and a fork or spoon for crushing samples
- A selection of foods (lemon, tomato, cucumber, banana, milk, canned green beans, canned tomatoes, vinegar, a store pickle)
- A clean quart jar with lid, a saucepan and a knife
- Your lab notebook

Refrigerator Dill Pickle Spears

Serves 1 quart (about 16 spears) · Prep 15 min · Chill 24 hr

Ingredients

- 4–5 small pickling cucumbers (about 1 lb, 450 g), washed, blossom ends trimmed, cut into spears
- 1 cup (240 mL) distilled white vinegar (5% acidity)
- 1 cup (240 mL) water
- 1 tablespoon (about 17 g) canning or kosher salt
- 1 teaspoon sugar
- 3 cloves garlic, smashed; 1 teaspoon dill seed or 3–4 sprigs fresh dill; ½ teaspoon black peppercorns

Method

1. Wash the jar in hot soapy water and rinse.
2. Heat the vinegar, water, salt and sugar in a saucepan just until the salt dissolves. Let it cool 10 minutes.
3. Pack the garlic, dill and peppercorns into the jar, then the cucumber spears, standing upright and tight.

4. Pour the brine over them to cover completely, leaving ½ inch of space. Lid the jar.
5. Refrigerate at least 24 hours before eating. Keep refrigerated and eat within 1 month.
6. Wash the saucepan and board.

Allergy check: Contains none of the major allergens.

Steps

1. **Predict.** Before testing, sort the foods into "below 4.6" and "above 4.6."
2. **Test.** Crush or squeeze a little of each food in a cup with a few drops of distilled water if needed, touch a pH strip to it, and record the pH.
3. **Sort.** Compare your results with your predictions and with published values.
4. **Pickle.** Make the refrigerator pickles. Record the brine's pH and the cucumber's pH before pickling.
5. **Track.** Test the pH of a sliver from the center of a spear at 1, 3 and 7 days.
6. **Graph** the pickle's pH against time with the 4.6 line marked.
7. **Conclusion.** Explain why pickles can be made safe with acid but green beans must be pressure canned.
8. Clean up.

Tips

- Use pickling cucumbers (small, firm, thin-skinned); salad cucumbers go soft.
- Trim the blossom end: it holds enzymes that soften pickles.
- Use canning or kosher salt without iodine or anti-caking agents, which cloud the brine.

Check your work

- ☐ I can explain how van Ermengem discovered the cause of botulism.
- ☐ I can explain why pH 4.6 divides boiling-water canning from pressure canning.
- ☐ I measured food pH and made refrigerator pickles safely.

LAB NOTEBOOK

1. Draw a pH scale from 2 to 8 and place each food you tested on it, with the 4.6 line in red.
2. Make a two-column chart: “boiling-water bath” foods and “pressure canner” foods.
3. Graph the pickle pH over a week.

KEY FORMULAS

$$[\mathrm{H}^+] = 10^{-\mathrm{pH}}$$

$$\%\,\text{acid after dilution} = \%\,\text{acid}_{\text{vinegar}} \times \frac{V_{\text{vinegar}}}{V_{\text{total}}}$$

From history. Botulinum toxin is so powerful that tiny, purified amounts are used as a medicine to relax muscles in certain medical conditions, under a doctor’s care. In the kitchen it is entirely prevented by correct acidity, temperature, pressure canning and refrigeration.

WORKED EXAMPLES

Example 1. A brine is 1 cup of 5% vinegar and 1 cup of water. What is its acid percentage?

Show solution

1. $5\% \times \frac{1}{2} = 2.5\%$.

Answer: 2.5% acetic acid. Tested refrigerator-pickle recipes use about this ratio or more vinegar.

Example 2. Canned green beans have a pH of about 5.6 and pickles about 3.5. How many times more H^+ do the pickles have? Which side of 4.6 is each on?

Show solution

1. $10^{5.6-3.5} = 10^{2.1} = 126$.

Answer: About 126 times more acidic. Green beans are low-acid (above 4.6, must be pressure canned); pickles are high-acid (below 4.6).

Example 3. Convert the pressure-canning temperature, 240 °F, and the boiling-water-bath temperature, 212 °F, to Celsius.

Show solution

1. $\frac{5}{9}(240 - 32) = 116\ ^\circ\text{C}$; $\frac{5}{9}(212 - 32) = 100\ ^\circ\text{C}$.

Answer: 116 °C and 100 °C. Only the higher temperature, reached under pressure, reliably destroys botulinum spores.

Example 4. In the Ellezelles outbreak, 34 of the musicians who ate the ham became ill and 3 died. What percentage of those who became ill died (the case-fatality rate)?

Show solution

1. $\dfrac{3}{34} \times 100\% = 8.8\%$.

Answer: About 9% of those who became ill died, a high fatality rate for a foodborne illness, which is why the canning rules are strict.

PRACTICE

1. Easy What bacterium causes botulism?

   Show answer

   Clostridium botulinum.

2. Easy What pH divides high-acid from low-acid foods in canning?

   Show answer

   4.6.

3. Easy Why do botulinum spores survive boiling?

   Show answer

   Spores are tough, dormant forms that resist heat; they need about 240 °F (pressure canning) to be destroyed.

4. Medium Name two high-acid and two low-acid foods.

   Show answer

   High-acid: most fruits, pickles, jams. Low-acid: green beans, corn, meat, soups.

5. Medium How many times more acidic is pH 3.6 than pH 4.6?

Show answer

10 times.

6. Medium Mix 2 cups of 5% vinegar with 1 cup of water. Find the acid percentage.

Show answer

$5\% \times 2/3 = 3.3\%$

7. Medium Why can a sealed jar be dangerous even though it was boiled?

Show answer

Boiling does not destroy spores; in a sealed, oxygen-free, low-acid food they can germinate and make toxin.

8. Medium What did van Ermengem find at Ellezelles?

Show answer

A bacterium in the ham and in a victim that grew only without oxygen and made a paralyzing toxin.

9. Hard Why are tomatoes canned with added lemon juice or citric acid in tested recipes?

Show answer

Many tomato varieties are near pH 4.6; added acid makes sure every jar is safely below it.

10. Hard Botulinum toxin is destroyed by boiling for 10 minutes, but spores are not. Why does that not make low-acid canned food safe to keep at room temperature?

Show answer

Spores surviving in the jar can grow and make new toxin during storage; reheating before eating is a last safety step but cannot be relied on, and the food must be processed to kill spores in the first place.

11. **Challenge** A family wants to can green beans in a boiling-water bath because they do not own a pressure canner. Explain, using spores, pH and temperature, why this is unsafe, and what they could do instead.

    Show answer

    Green beans are low-acid (pH about 5–6); boiling at 212 °F does not destroy spores, and with no oxygen and low acid the spores can grow and make toxin. Instead, freeze the beans, pickle them with a tested acid recipe, or pressure can with an adult using a tested NCHFP recipe.

COMMON MISTAKES

- Using a family recipe or an internet recipe instead of a tested canning recipe.
- Reducing vinegar or using homemade vinegar of unknown strength.
- Water-bath canning low-acid vegetables.
- Tasting food from a bulging or leaking can to “see if it’s okay.”

> **Make it a game · Above or Below 4.6.** Your parent names foods: pickles, plain green beans, tomatoes with added lemon juice, corn, peaches. Call above or below pH 4.6 and the safe canning method that fits. Explain why botulism spores cannot be trusted in sealed, low-acid jars. Discuss, but do not try canning today. Tell how van Ermengem found the bacterium.

8.4 Canning and Pasteurization: Nathan Straus's Milk Stations

OBJECTIVES

- Tell how heat preservation grew from Appert's bottles and Pasteur's heat treatment to Nathan Straus's pasteurized-milk stations in New York (from 1893).
- Explain thermal death of microbes with D-values and the 12D concept, and compare pasteurization with sterilization.
- Make strawberry jam with a parent and process it in a boiling-water bath using a tested recipe, adjusting for altitude.

> **Warm-up.** Look at the labels on a carton of milk, a jar of jam and a can of soup. What processes do they mention (pasteurized, ultra-pasteurized, sterilized)? Which must be refrigerated, and which can sit in the pantry until opened? Why might that be?

WATCH

Canning Strawberry Jam

University of Illinois Extension · 3:06

https://www.youtube.com/watch?v=p8qc1_v04ao

> **WHEN TO WATCH**
> Before the lab. Watch every step of filling, lidding and processing the jars, especially headspace and the processing time.

BACKUP VIDEO

The Science of Canning | Year-Round Gardening

wpsu · 3:15

https://www.youtube.com/watch?v=9MN9X-pnjaY

During session 1. A Penn State Extension educator explains high-acid and low-acid foods and the two canning methods.

KEY TERMS

pasteurization

Heating food (such as milk or juice) enough to kill harmful vegetative microbes, without sterilizing it. Pasteurized milk must still be refrigerated.

sterilization (commercial)

Heating sealed food enough to destroy all microbes and spores that could grow under normal storage, as in canned low-acid foods.

D-value

The time at a given temperature needed to kill 90% (one log) of a microbe population.

12D process

Heating long enough for twelve D-values, reducing *C. botulinum* spores by a factor of 10^{12}; the standard for commercially canned low-acid foods.

headspace

The space left between the food and the lid of a jar, needed for a proper vacuum seal.

pectin

A carbohydrate from fruit cell walls that forms a gel with sugar and acid; it sets jam.

CORE IDEAS

The story. In the 1890s milk sold in American cities was often dirty, warm and days old, and it carried diseases such as tuberculosis, typhoid and scarlet fever. Many babies in crowded city neighborhoods died each summer. Nathan Straus, a New York merchant and part-owner of Macy's department store, learned of the work of Pasteur and other scientists showing that heating milk killed disease germs. In 1893 he opened the first of many milk stations in New York City that sold or gave away pasteurized milk to poor families. Over the next decades he campaigned tirelessly for pasteurization laws, and infant deaths in the city fell sharply as clean, pasteurized milk spread.

How they figured it out. Appert had shown that sealing and heating preserved food (Lesson 1.1). In the 1860s Pasteur showed that gentle heating killed spoilage microbes without ruining a food's flavor, and in 1886 the German chemist Franz von Soxhlet proposed heating milk for infants. Twentieth-century food scientists made heat treatment precise by measuring how fast heat kills each microbe: its **D-value.**

Knowing the most heat-resistant dangerous microbe in a food lets scientists calculate a safe process.

The kitchen science. Heat kills microbes in a predictable, logarithmic way: each D-value of time at a temperature kills 90%. Milk pasteurization targets heat-sensitive pathogens: 161 °F (72 °C) for 15 seconds, or 145 °F (63 °C) for 30 minutes. Commercial canning of low-acid food targets *C. botulinum* spores, whose D-value at 250 °F (121 °C) is about 0.21 minute; a **12D process** is therefore about 2.5 minutes at 250 °F at the slowest-heating point in the can. Home canning follows tested recipes that build in this kind of safety. High-acid foods like jam need only a boiling-water bath, because acid already stops spores. In jam, **pectin** from the fruit (or added) forms a gel when there is enough sugar (about 65%) and acid (about pH 3.0–3.4); sugar binds water and lowers water activity, helping the jam keep.

Let's cook. With a parent, you will make strawberry jam from a tested pectin recipe and process it in a boiling-water bath. The skill is **following a tested recipe exactly**: measuring precisely, leaving correct headspace, and processing for the right time for your altitude.

PICTURE STUDY



Display of Home-Canned Food, Farm Security Administration photographer, c. 1940 · Photograph · Library of Congress, Washington, D.C.

Image: Wikimedia Commons, public domain

During the 1930s and 1940s farm families and home-demonstration clubs canned huge quantities of food at home. Proud displays like this one were common at county fairs and community exhibits.

Look closely

- Look at the jars. Which foods can you recognize?
- Which jars hold high-acid foods and which hold low-acid foods? Which method would each need?
- Look at how full each jar is. What is the space at the top called, and why is it needed?
- How many meals might these shelves provide in winter?

Talk about it

1. Before freezers were common, why was home canning so important to farm families?
2. Why did extension services teach tested canning methods so carefully?
3. Joseph stored grain in Egypt for the years of famine (Genesis 41). How is a pantry of canned food like his storehouses?

Safety first. Boiling-water canning is done only with a parent present. Jars, water and jam are extremely hot: use a jar lifter, set the canner on a back burner, lower jars upright into the water, lift the lid away from you, and let jars cool undisturbed. Follow a tested recipe exactly; do not reduce sugar, acid or processing time in a pectin recipe. Do not taste the boiling jam; it causes severe burns. Any jar that does not seal goes in the refrigerator and is used within 3 weeks.

KITCHEN LAB

Jam by a Tested Recipe

You will make strawberry jam with powdered pectin, process it in a boiling-water bath with a parent, measure its Brix and pH, and record whether every jar seals.

You will need

- A large, deep pot or canner with a rack (water must cover jars by 1–2 inches)
- 6–7 half-pint canning jars with new two-piece lids
- A jar lifter, a canning funnel, a ladle and a headspace tool or ruler
- A large heavy pot for the jam, a potato masher and a timer
- pH test strips
- Your lab notebook

Strawberry Jam (Powdered Pectin, Boiling-Water Bath)

Serves About 7 half-pint jars · Prep 30 min · Cook 15 min · Process 10 min (plus altitude time) · Cool 24 hr

Ingredients

- About 2 quarts fresh ripe strawberries, washed, hulled and crushed to make exactly 5 cups (1.2 L) crushed fruit
- 1 box (1.75 oz, 49 g) powdered fruit pectin
- 7 cups (1.4 kg) sugar, measured exactly into a separate bowl
- ½ teaspoon butter (optional, reduces foaming)

Method

1. Read the instructions in your pectin box and follow them if they differ from these; the box recipe is the tested recipe for that pectin.
2. Wash the jars, lids and bands in hot soapy water. Keep the jars hot in the canner water (simmering, not boiling) until you fill them.
3. Put the crushed strawberries in the large pot and stir in the pectin (and butter). Bring to a full rolling boil that cannot be stirred down, over high heat, stirring constantly.

4. Add all the sugar at once. Return to a full rolling boil and boil exactly 1 minute, stirring constantly. Remove from the heat and skim off foam.
5. With a parent: ladle the hot jam into hot jars through the funnel, leaving ¼ inch headspace. Wipe the rims clean, put on lids and screw bands just fingertip-tight.
6. Lower the jars into the canner on the rack; the water must cover them by 1–2 inches. Bring to a full boil, cover, and process half-pints 10 minutes at 0–1,000 ft (add 5 minutes at 1,001–6,000 ft and 10 minutes above 6,000 ft).
7. Turn off the heat, remove the lid, wait 5 minutes, then lift the jars straight up onto a towel. Let them cool undisturbed 12–24 hours.
8. Check seals: lids should be curved down and not flex. Label and store sealed jars in a cool, dark place for up to a year; refrigerate any unsealed jar and opened jars.

Allergy check: Contains milk only if the optional butter is used. Strawberries can cause reactions in some people.

Steps

1. **Altitude.** Look up your altitude and write your processing time before you start.
2. **Measure** the crushed fruit and sugar exactly; record their masses.
3. **Brix.** Calculate the jam's approximate sugar percentage (strawberries are about 7% sugar). Is it near the 65% needed for a set?
4. **pH.** Test the pH of the crushed fruit and of a cooled spoonful of finished jam.
5. **Process** the jars with a parent, recording the time the water returned to a boil and the time processing ended.
6. **Seals.** After 24 hours, check every jar and record which sealed.
7. **Set test.** Open one jar after 2 days (jam can take that long to set) and describe the gel.
8. **Conclusion.** Explain the roles of heat, acid, sugar, pectin and the vacuum seal in keeping jam safe.

Tips

- Do not double a pectin jam recipe; large batches often fail to set.
- Start timing only when the water returns to a full boil with the jars in.
- A “ping” as jars cool is the lid being pulled down by the vacuum: the sound of a good seal.

Check your work

- ☐ I can explain pasteurization, sterilization, D-values and the 12D process.
- ☐ I can explain why jam is canned in a boiling-water bath and how altitude changes processing time.
- ☐ I made and processed jam with a parent using a tested recipe.

LAB NOTEBOOK

1. Draw a sealed jar of jam and label the headspace, the vacuum, the lid and the gel, with notes on acid, sugar and pectin.
2. Graph log(number of microbes) against heating time for a D-value of 2 minutes.
3. Record your jam data: masses, Brix estimate, pH, processing times and seals.

KEY FORMULAS

$$N = N_0 \cdot 10^{-t/D}$$

$$\text{process time for } n \text{ log reductions} = n \times D$$

From history. Nathan Straus also gave away food and coal to the poor during the hard winter of 1892–93 and funded milk stations and health work in other cities and abroad. Ultra-high-temperature (UHT) milk, heated to about 280 °F (138 °C) for a few seconds and packed in sterile cartons, can be kept unrefrigerated until opened.

WORKED EXAMPLES

Example 1. *C. botulinum* spores have $D_{121\,^\circ\text{C}} \approx 0.21$ min. How long at 121 °C gives a 12D process?

Show solution

1. $12 \times 0.21 \text{ min} = 2.52 \text{ min}.$

Answer: About 2.5 minutes at 121 °C at the coldest point in the can. (Real processes are longer because the center of the can takes time to heat.)

Example 2. A can starts with 1,000 (10^3) spores. After a 12D process, how many remain on average? What does that mean for a billion cans?

Show solution

1. $10^3 \times 10^{-12} = 10^{-9}$ spores per can.
2. In 10^9 cans, about 1 spore would survive in total.

Answer: About one surviving spore in a billion cans: the margin of safety behind commercial canning.

Example 3. A milk pathogen has $D_{72\,^\circ\text{C}} = 2.5$ seconds. How many log reductions does 15-second pasteurization give?

Show solution

1. $\dfrac{15\text{ s}}{2.5\text{ s}} = 6.$

Answer: 6 log reductions: 99.9999% of that pathogen killed.

Example 4. A jam recipe says to process half-pint jars 10 minutes at up to 1,000 ft, adding 5 minutes from 1,001 to 6,000 ft and 10 minutes above 6,000 ft. Find the time at 4,500 ft and at 7,200 ft, and explain why.

Show solution

1. 4,500 ft: $10 + 5 = 15$ min.
2. 7,200 ft: $10 + 10 = 20$ min.

Answer: 15 and 20 minutes. Water boils at a lower temperature at altitude (about 203 °F at 4,500 ft), so killing microbes takes longer.

PRACTICE

1. Easy What is a D-value?

   Show answer

   The time at a set temperature to kill 90% of a microbe population.

2. Easy Give the two common milk pasteurization conditions.

   Show answer

   161 °F (72 °C) for 15 seconds; 145 °F (63 °C) for 30 minutes.

3. **Easy** In what year did Nathan Straus open his first milk station?

Show answer

1893.

4. **Medium** With D = 0.21 min, how many minutes for a 5-log reduction?

Show answer

1.05 min.

5. **Medium** 10^6 microbes, D = 3 min. How many remain after 12 minutes?

Show answer

$10^6 \times 10^{-4} = 100$

6. **Medium** Why can jam be processed in a boiling-water bath, while green beans cannot?

Show answer

Jam is high-acid (below pH 4.6), so botulinum spores cannot grow; green beans are low-acid and need pressure canning to destroy spores.

7. **Medium** Why must you add processing time at higher altitudes?

Show answer

Water boils at a lower temperature, so microbes die more slowly.

8. **Medium** What three things must be in balance for pectin to set jam?

Show answer

Pectin, sugar (about 65%) and acid (about pH 3.0–3.4).

9. **Hard** Why does pasteurized milk still need refrigeration, while canned soup does not?

Show answer

Pasteurization kills pathogens but not all spoilage microbes or spores; canning sterilizes the sealed food so nothing can grow at room temperature.

10. **Hard** Estimate the sugar percentage of the jam: 5 cups crushed strawberries (1,200 g at 7% sugar) and 1,400 g sugar, with about 150 g water evaporated.

Show answer

$(84 + 1400)/(2600 - 150) = 1484/2450 = 61\%$

11. **Challenge** A home canner wants to reduce the sugar in a regular pectin recipe by half. Explain what may go wrong and what safe alternatives exist.

    Show answer

    Regular pectin needs high sugar to gel, and sugar also lowers water activity; the jam may not set and may mold sooner. Use a tested low- or no-sugar pectin recipe, or make refrigerator or freezer jam.

COMMON MISTAKES

- Using an untested family recipe or reducing sugar in a regular pectin recipe.
- Not adjusting processing time for altitude.
- Overtightening bands, which keeps air from venting and can cause seal failures.
- Moving or tilting jars while they cool and seal.

> **Make it a game · D-Value Drill.** Your parent gives a starting count, such as one million microbes, and a D-value of two minutes. Calculate the time to reduce the count to one, then to a 12D process. Run six variations and race a timer. Tell how Nathan Straus's milk stations used pasteurization to protect city children.

8.5 Freezing and Ice Crystals: Clarence Birdseye

OBJECTIVES

- Tell how Clarence Birdseye learned fast freezing from the Inuit in Labrador (about 1912–1915) and launched frozen foods in 1930.
- Explain why fast freezing makes small ice crystals and better texture, and calculate the energy to freeze food.
- Blanch and freeze green beans two ways, measure drip loss, and make freezer breakfast burritos.

> **Warm-up.** Compare a strawberry frozen slowly in a bag in the freezer and one frozen in seconds, if you have commercially frozen berries. Thaw both. Which is mushier? What do you think happened inside the slowly frozen one?

WATCH

Instant Ice Crystals - The Secret Life of Ice - BBC

BBC · 2:28

https://www.youtube.com/watch?v=3Qasw7lb2UM

> **WHEN TO WATCH**
> During session 1. Watch how quickly crystals grow in supercooled water, and think about what large crystals would do inside the cells of food.

BACKUP VIDEO

How Clarence Birdseye Created the Frozen Food Aisle

Everything Everywhere (Everything Everywhere) · 9:48

https://www.youtube.com/watch?v=6KZB2f1BdS0

Any time in this lesson. An audio history (with a still picture) of Clarence Birdseye's life, from fur trading in Labrador to the frozen-food aisle.

KEY TERMS

fast (quick) freezing

Freezing food so quickly that water forms many small ice crystals that do little damage to cells.

ice crystal growth

In slow freezing, fewer, larger crystals grow, piercing and tearing cell walls; the food leaks water (drip) when thawed.

blanching

Briefly boiling or steaming vegetables before freezing to inactivate enzymes that would otherwise slowly spoil flavor, color and texture.

freezer burn

Dry, discolored patches on frozen food caused by ice turning directly to vapor (sublimation) where food is exposed to air.

drip loss

The liquid lost from thawed food, as a percentage of its frozen mass; a measure of freezing damage.

CORE IDEAS

The story. Clarence Birdseye was a naturalist from Brooklyn who worked as a fur trader in Labrador, in far northeastern Canada, from about 1912 to 1915. He watched Inuit fishermen pull fish through holes in the ice into air far below zero, where the fish froze almost instantly. Months later, cooked, the fish tasted nearly fresh, far better than the slowly frozen food sold in New York. Back home, Birdseye developed machines that froze packaged food quickly between refrigerated metal plates. His company introduced frozen foods to shoppers in Springfield, Massachusetts, on March 6, 1930, under the name Birds Eye.

How they figured it out. Birdseye reasoned that the difference between the Inuit's fish and store-bought frozen fish was speed. Under a microscope, slowly frozen tissue showed large ice crystals that had torn the cells; quickly frozen tissue showed tiny ones. He also realized that food had to be frozen in flat packages, so heat could leave quickly, and in its retail package, so it was never thawed and refrozen. He received many patents and is considered the founder of the modern frozen-food industry.

The kitchen science. Freezing preserves food by turning its water into ice: the remaining liquid becomes too concentrated, and too cold, for microbes to grow (most stop below about 14 °F, −10 °C), though freezing does not kill most of them. To freeze food, you must remove its sensible heat and then its large latent heat of fusion, about 334 J for every gram of water (Lesson 2.3). The faster heat is removed, the more crystals start at once and the smaller they stay; slow freezing lets a few crystals grow large and puncture cell walls, so thawed food drips and turns mushy. Enzymes still work slowly in the freezer, which is why vegetables are **blanched** first. Air contact causes **freezer burn**, so food should be wrapped tightly. A home freezer at 0 °F (−18 °C) keeps food safe indefinitely, though quality slowly declines.

Let's cook. You will blanch and freeze green beans by two methods and measure drip loss, and you will make a batch of breakfast burritos to freeze for quick, safe breakfasts. The skill is **freezing for quality**: cool food quickly, freeze it flat and spread out, and wrap it airtight.

PICTURE STUDY



Clarence Birdseye, Unknown photographer, 1930 · Photograph · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Clarence Birdseye (1886–1956) held hundreds of patents. He is remembered as the man who brought quick-frozen foods to the grocery store.

Look closely

- Look at his face and clothing. What kind of man do you think he was?
- Imagine him years earlier in Labrador, fishing through the ice. What would he have worn?
- This was taken in the year frozen foods first went on sale. What might he be thinking about?

Talk about it

1. Birdseye learned from the Inuit. What can scientists learn from traditional ways of preparing food?
2. Why did frozen food become common only after many homes had electric freezers?
3. How has frozen food changed the way families eat through the winter?

Safety first. Blanching uses a large pot of boiling water: lower beans in with a basket or spider and lift them out the same way, away from your body. Cook the burrito filling thoroughly (eggs to 160 °F, sausage to 160 °F), cool it quickly before wrapping, and reheat frozen burritos to 165 °F (74 °C) in the center. Label and date all frozen food.

KITCHEN LAB

Fast Freeze vs. Slow Freeze

Does freezing speed change drip loss and texture? You will blanch green beans, freeze one batch spread on a tray (fast) and one batch packed in a deep container (slow), thaw both and compare.

You will need

- 1 lb (450 g) fresh green beans
- A large pot, a spider or slotted spoon, and a big bowl of ice water
- A rimmed sheet pan lined with parchment, and a deep plastic container
- A digital scale and a colander
- Freezer bags or plastic wrap and foil; a marker
- Your lab notebook

Freezer Breakfast Burritos

Serves 10 burritos · Prep 30 min · Cook 25 min · Freeze 2 hr

Ingredients

- 1 lb (450 g) breakfast sausage (or 2 cans black beans, drained, for meatless)
- 1½ lb (680 g) potatoes, diced small (or 4 cups frozen diced hash browns)
- 2 tablespoons oil, salt and pepper
- 10 large eggs, beaten with ¼ cup milk
- 2 cups (225 g) shredded cheddar
- 10 large (10-inch) flour tortillas
- Salsa for serving

Method

1. Brown the sausage in a large skillet until it reaches 160 °F (71 °C); drain on a plate.
2. Cook the potatoes in the oil over medium heat, covered for 8 minutes then uncovered, until tender and browned. Season.

3. Scramble the eggs in the skillet over medium-low heat until set, with no liquid egg remaining (160 °F).
4. Spread the fillings on sheet pans and cool 15 minutes; then refrigerate until cool to the touch. (Warm filling makes soggy burritos and freezes slowly.)
5. Divide the potatoes, sausage, eggs and cheese among the tortillas. Fold in the sides and roll tightly. Wrap each in plastic wrap and then foil; label and date.
6. Freeze flat on a sheet pan, then stack in a freezer bag. Keep up to 3 months.
7. To reheat: unwrap the foil, wrap in a damp paper towel and microwave 2–3 minutes, turning once, until 165 °F in the center.

Allergy check: Contains wheat (tortillas), eggs, milk (cheese, milk). Sausage may contain soy or other allergens; check the label. For wheat-free, use gluten-free tortillas or make breakfast bowls.

Steps

1. **Hypothesis.** Predict which method will lose more liquid on thawing and have a softer texture.
2. **Blanch.** Boil the beans 3 minutes (timing from the return to a boil), then plunge into ice water for 3 minutes. Drain and pat dry.
3. **Divide.** Weigh two 200 g portions. Spread one in a single layer on the lined sheet pan (fast). Pack the other tightly into the deep container (slow). Freeze both.
4. **Time.** Check every 30 minutes: how long until each is frozen solid?
5. **Thaw.** The next day, thaw both portions in the refrigerator in a colander over a bowl for 6 hours. Weigh the drained beans and calculate drip loss.
6. **Compare** texture by bending and tasting (after cooking both briefly).
7. **Make** the freezer burritos, cooling and freezing them flat.
8. **Conclusion.** Explain your results with ice crystal size and cell damage.

Tips

- Freeze foods flat in thin bags; they freeze faster, stack well and thaw faster.
- Squeeze air out of freezer bags to prevent freezer burn.

- Do not overload the freezer with warm food at once; add a little at a time.

Check your work

- ☐ I can tell how Birdseye developed fast freezing.
- ☐ I can explain ice-crystal size, blanching and freezer burn, and calculate the energy to freeze food.
- ☐ I measured drip loss from fast and slow freezing and made a freezer meal safely.

LAB NOTEBOOK

1. Draw plant cells after fast freezing (small crystals) and slow freezing (large crystals tearing the cells).
2. Record times to freeze, masses and drip loss in a table.
3. Make a freezer inventory sheet for your family's freezer with dates.

KEY FORMULAS

$$q = mc_{\text{water}}\Delta T_1 + mL_f + mc_{\text{ice}}\Delta T_2$$

$$\text{drip loss } \% = \frac{m_{\text{frozen}} - m_{\text{thawed, drained}}}{m_{\text{frozen}}} \times 100\%$$

From history. Birdseye sold his company in 1929 to the Postum Company and Goldman Sachs for about $22 million; Postum then renamed itself General Foods. Home freezers became common in American homes after World War II, and frozen vegetables, fruits and complete meals followed.

WORKED EXAMPLES

Example 1. How much heat must be removed to freeze 500 g of green beans (about 90% water) from 20 °C to −18 °C? Treat the beans as water above freezing (c = 4.18 J/(g·°C)) and ice below (c = 2.1 J/(g·°C)); only the water freezes.

Show solution

1. Cool to 0 °C: $500 \times 4.18 \times 20 = 41{,}800$ J.
2. Freeze the water: $0.90 \times 500 \times 334 = 150{,}300$ J.
3. Cool to −18 °C: $500 \times 2.1 \times 18 = 18{,}900$ J.
4. Total: 211,000 J.

Answer: About 211 kJ, of which more than 70% is latent heat. That is why freezing takes far longer than chilling.

Example 2. A home freezer removes heat from a load of food at an average of 60 W. How long would it take to remove the 211 kJ above?

Show solution

1. $t = \dfrac{211{,}000 \text{ J}}{60 \text{ W}} = 3517 \text{ s} \approx 59 \text{ min}$.

Answer: About an hour at best; a crowded freezer or a deep container takes much longer, which is why small, flat packages freeze better.

Example 3. Fast-frozen beans weigh 200 g frozen and 192 g after thawing and draining; slow-frozen beans weigh 200 g and 176 g. Find each drip loss.

Show solution

1. Fast: $\dfrac{8}{200} \times 100\% = 4\%$. Slow: $\dfrac{24}{200} \times 100\% = 12\%$.

Answer: 4% and 12%: slow freezing tripled the drip loss.

Example 4. Blanching time for green beans is 3 minutes. How much energy does 2 kg of boiling water lose when 500 g of beans at 20 °C are added, if the beans warm to 95 °C (take c = 3.9 J/(g·°C) for beans)? What does that suggest about pot size?

Show solution

1. $q = 500 \times 3.9 \times 75 = 146{,}000\ \text{J}$.
2. Water drop: $\Delta T = \dfrac{146{,}000}{2000 \times 4.18} = 17\ ^\circ\text{C}$.

Answer: The water could drop about 17 °C, well below boiling. Blanch in a large pot (at least 1 gallon of water per pound of vegetables) and start timing when it boils again.

PRACTICE

1. Easy Where did Birdseye learn about fast freezing?

   Show answer

   In Labrador, watching Inuit fishermen freeze fish in very cold air.

2. Easy What temperature should a home freezer be?

   Show answer

   0 °F (−18 °C) or below.

3. Easy Why blanch vegetables before freezing?

   Show answer

   To inactivate enzymes that would slowly spoil color, flavor and texture in the freezer.

4. Medium Why does slow freezing make food mushy?

   Show answer

   Fewer, larger ice crystals grow and tear cell walls, so cells leak water when thawed.

5. Medium Does freezing kill bacteria? Explain.

   Show answer

   Mostly not; it stops their growth. They can grow again when food thaws.

6. **Medium** Find the heat to freeze 200 g of water at 0 °C.

Show answer

$$200 \times 334 = 66{,}800 \text{ J}$$

7. **Medium** What causes freezer burn?

Show answer

Ice sublimating from food surfaces exposed to air, leaving dry, discolored patches.

8. **Medium** A package weighs 300 g frozen and 279 g thawed and drained. Find drip loss.

Show answer

7%.

9. **Hard** Estimate the heat removed in freezing 1.0 kg of strawberries (90% water) from 20 °C to −18 °C, using the method of Worked Example 1.

Show answer

$$83{,}600 + 300{,}600 + 37{,}800 \approx 422 \text{ kJ}$$

10. **Hard** Why did Birdseye freeze food in its final retail packages?

Show answer

So it was never thawed and refrozen and was protected from air; flat packages also freeze quickly between plates.

11. **Challenge** A burrito's center must reach 165 °F when reheated. Why does the center lag behind the outside in a microwave, and how does the recipe handle it?

Show answer

Microwaves heat the outer few centimeters; the frozen center must also absorb latent heat to melt and then be heated by conduction. The recipe uses moderate power, turns the burrito, and checks the center with a thermometer.

COMMON MISTAKES

- Freezing food in thick blocks or deep containers.
- Skipping blanching for vegetables.
- Wrapping and freezing hot food.

- Thawing meat on the counter instead of in the refrigerator, cold water or microwave.

> **Make it a game · Freezer Story Chain.** Take turns telling the story of Clarence Birdseye in Labrador, one sentence each. Every sentence must use one of these terms: fast freezing, ice crystal growth, blanching, freezer burn, drip loss. The first to repeat or stall loses. Then each of you sketches a small and a large ice crystal in a cell.

UNIT 8

Preservation

For most of history, food that was not preserved was soon lost. This unit studies the five great ways people keep food: drying, salting and sugaring, acid, heat, and cold. Each works by attacking the conditions microbes need: water activity, acidity, temperature and time. You will learn the science behind each method and the rules that make home preservation safe.

The stories follow W. J. Scott's discovery of water activity, the salt fishermen of the Grand Banks, Émile van Ermengem's investigation at Ellezelles, Nathan Straus's pasteurized-milk stations and Clarence Birdseye's frozen fish. The labs measure moisture loss, osmosis, the pH of foods, jam's seals and the drip loss of frozen beans. The recipes are apple chips, brined pork tenderloin, refrigerator pickles, strawberry jam processed with a parent, and freezer breakfast burritos.

PREREQUISITES

- Unit 2: latent heat, boiling point and altitude
- Unit 6: pH, lactic fermentation and vinegar
- Unit 7: pathogens, FAT TOM and log reductions

MASTERY CHECKLIST

- ☐ I can explain water activity and calculate moisture content and water removed.
- ☐ I can explain osmosis and how salt and sugar preserve, and make a brine by mass percent.
- ☐ I can explain botulism, spores and the pH 4.6 line, and why low-acid foods need pressure canning.
- ☐ I can explain pasteurization, sterilization, D-values and the 12D process, and adjust canning time for altitude.
- ☐ I can explain fast and slow freezing, blanching and freezer burn, and calculate the energy to freeze food.
- ☐ I preserved food safely by drying, brining, pickling, canning with a parent and freezing.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **National Center for Home Food Preservation**: Free. The University of Georgia's tested recipes and guides for canning, pickling, freezing and drying. Use only tested recipes for canning.
- **A boiling-water canner with a rack and a jar lifter**: Needed only for Lesson 8.4. A large, deep stockpot with a rack or a folded towel in the bottom can work if the water covers the jars by 1–2 inches.
- **A mandoline slicer with a hand guard**: Optional, for even apple slices in Lesson 8.1. Use only with the guard and a parent present.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

8.1 Drying and Water Activity: W. J. Scott's Discovery

3 sessions of 50–90 minutes (plus 2–3 hours of drying)

8.2 Salt, Sugar and Osmosis: The Salt of the Earth

3 sessions of 50–90 minutes (plus 1–8 hours of brining)

8.3 Acid and pH 4.6: Van Ermengem and the Botulism Line

3 sessions of 50–90 minutes

8.4 Canning and Pasteurization: Nathan Straus's Milk Stations

3 sessions of 60–90 minutes

8.5 Freezing and Ice Crystals: Clarence Birdseye

3 sessions of 50–90 minutes (plus freezing time)

Unit 8 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**

   Define water activity and give the approximate a_w below which most bacteria, most molds, and all microbes stop growing.

2. **7 pts**

   500 g of pears at 84% water are dried to 18% moisture. Find the final mass and the water removed.

3. **6 pts**

   Explain how salting preserves fish, using osmosis and water activity.

4. **6 pts**

   How much salt makes a 6% brine with 1,500 g of water?

5. **5 pts**

   A slice goes from 9.0 g to 8.1 g in a solution. Find the percent change and say whether the solution was hypertonic or hypotonic.

6. **6 pts**

   What did van Ermengem discover in 1895, and what clue showed the organism grew without air?

7. **7 pts**

   Explain why pH 4.6 divides boiling-water canning from pressure canning.

8. **5 pts**

   Mix 3 cups of 5% vinegar with 1 cup of water. Find the acid percentage.

9. **7 pts**

   With $D_{121} = 0.21$ min, find the time for a 12D process. If a can starts with 100 spores, how many survive on average?

10. **6 pts**

    Why did Nathan Straus's pasteurized-milk stations save lives?

11. **5 pts**

    A jam recipe says 10 minutes for half-pints at sea level. Find the time at 5,500 ft and at 7,000 ft.

12. **6 pts**

    Explain why fast freezing gives better texture than slow freezing.

13. **7 pts**

    Find the heat removed in freezing 800 g of water from 15 °C to −18 °C (c_{water} 4.18, c_{ice} 2.1, L_f 334 J/g).

14. **6 pts**

    Why are vegetables blanched before freezing, and why is jam not blanched?

15. **15 pts**

    Short essay (6–8 sentences): Choose a food your family eats and explain how it could be preserved by two different methods from this unit. For each method, explain which FAT TOM factor it controls, what the safety rules are, and what happens to quality.

ANSWER KEY

1. The ratio of water vapor pressure above a food to that above pure water (free water). About 0.91 (most bacteria), 0.80 (most molds), 0.60 (all microbes).
2. Solids 80 g; final $80 / 0.82 = 97.6$ g; water removed 402 g.
3. Salt draws water out of the fish and out of microbes by osmosis, and binds water so the water activity falls below what bacteria need.
4. $m = 0.06(m + 1500) \Rightarrow m = 95.7$ g
5. −10%; hypertonic.
6. He identified the bacterium (now *C. botulinum*) that makes botulinum toxin; it grew deep inside the ham and in his laboratory only when air was excluded.
7. Below pH 4.6, botulinum spores cannot germinate, so the 212 °F boiling bath (which kills other microbes) is enough; above it, spores must be destroyed at about 240 °F in a pressure canner.
8. 3.75%.
9. 2.52 min; $100 \times 10^{-12} = 10^{-10}$.
10. Pasteurization killed disease germs in city milk (such as those of tuberculosis and typhoid), so infants and children drinking it were far less likely to become sick or die.
11. 15 minutes; 20 minutes.
12. Fast freezing forms many small ice crystals that do little damage; slow freezing grows fewer, larger crystals that tear cells, causing drip and mushiness.
13. $50{,}160 + 267{,}200 + 30{,}240 = 347{,}600$ J
14. Blanching inactivates enzymes that would degrade frozen vegetables; jam is cooked and preserved by sugar, acid and heat processing.
15. Answers vary. Full credit for two correctly explained methods (drying, salting/sugaring, acidifying, heat processing, freezing), each linked to the factor it controls (moisture/water activity, acidity, temperature/time), accurate safety rules (tested recipes, pH 4.6, pressure canning for low-acid, 0 °F, blanching), and honest quality effects.

UNIT PROJECT: THE FAMILY PANTRY PLAN

Joseph planned ahead for seven lean years. Plan and carry out a small "preservation season" for your family: preserve at least three foods by three different methods from this unit (for example, dried apple chips, refrigerator pickles and frozen blanched vegetables, or jam processed with a parent). For each, keep a record of the tested recipe used, the safety controls, labels with dates, and any measurements (masses, pH, Brix, times).

Then write a two-page pantry plan: an inventory of your family's preserved foods with storage temperature and use-by dates, the science of how each is preserved, and a rotation plan so nothing is wasted. Serve a family meal that uses at least two of your preserved foods.

LOOK FOR	WHAT IT MEANS
Safety	Tested recipes followed exactly; correct pH, temperatures, altitude adjustments; canning only with a parent.
Records and labels	Complete records with measurements; every container labeled and dated.
Science	Correct explanation of how each method controls microbes and affects quality.
Pantry plan	Clear inventory, storage conditions and rotation plan.
Stewardship	Food used well, little waste, a family meal served with thanks.

UNIT 9

Taste, Smell and the Brain

Why does food taste good? This unit follows a bite of food from the tongue and nose to the brain. You will learn how taste receptors detect the five basic tastes, how Ikeda found the fifth, how smell creates most of what we call flavor, why people differ in how they taste bitterness, and how the brain's reward system and the body's fullness signals shape what and how much we want to eat.

The stories follow the tongue-map mistake and the discovery of taste receptors, Kikunae Ikeda's kombu broth, Linda Buck and Richard Axel's receptor genes, Arthur Fox's PTC dust and Linda Bartoshuk's supertasters, and Olds, Milner and the bliss point. The labs measure taste thresholds, umami synergy, smell's share of flavor, papillae and bitterness, and satiety. The recipes are a balanced tomato soup, dashi noodle soup, basil pesto pasta, roasted Brussels sprouts and a hearty lentil soup. Throughout, we talk about food as a good gift, enjoyed with thanks and self-control, never in terms of body size.

PREREQUISITES

- Unit 4: amino acids (for glutamate)
- Unit 3: sugars and fiber
- Basic probability, square roots and quadratic functions (vertex form)

MASTERY CHECKLIST

- ☐ I can describe taste buds and the receptors for the five basic tastes, and explain why the tongue map is a myth.
- ☐ I can explain umami, glutamate, ribonucleotides and synergy.
- ☐ I can explain retronasal smell and the combinatorial code of odor receptors.
- ☐ I can explain taste genetics with a Punnett square and allele frequencies, and how taste changes with age.
- ☐ I can explain dopamine as wanting, the bliss point and satiety signals, with no body-size talk.
- ☐ I can calculate dilutions, combinations, densities, energy density and a quadratic bliss point.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **Monell Chemical Senses Center**: Free articles and videos from a research institute devoted to taste and smell.
- **Blue food coloring and a small magnifying glass**: For the papillae count in Lesson 9.4.
- **PTC or thiourea taste strips**: Optional, with a parent's approval; inexpensive from science-education suppliers. The lab works without them.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

9.1 Taste Receptors and the Tongue-Map Myth — 3 sessions of 50–90 minutes

9.2	**Ikeda and Umami**	3 sessions of 50–90 minutes
9.3	**Smell and Flavor: Buck, Axel and the Receptor Genes**	3 sessions of 50–90 minutes
9.4	**Genetics of Taste: Fox's PTC and Bartoshuk's Supertasters**	3 sessions of 50–90 minutes
9.5	**Reward, Cravings and Satiety: Olds, Milner and the Bliss Point**	3 sessions of 50–90 minutes

Unit 9 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   Explain how the tongue map arose and what the evidence shows instead.

2. **6 pts**
   Name the receptor or mechanism for each of the five basic tastes.

3. **6 pts**
   How do you make 250 mL of a 0.4% salt solution from a 2% stock? What is the concentration after three more two-fold dilutions?

4. **6 pts**
   Describe Ikeda's discovery and name the two compounds that strengthen umami.

5. **6 pts**
   Ratings: kombu 2.5, shiitake 1.5, combined 7.0. Find the synergy factor and explain the result.

6. **6 pts**

   What did Buck and Axel discover, and how does a few hundred receptors code thousands of odors?

7. **5 pts**

   How many combinations of 3 receptors can be made from 350 types?

8. **6 pts**

   Explain why food tastes bland with a cold, using retronasal smell.

9. **6 pts**

   Two parents are Tt for the taster gene. What are the chances of TT, Tt and tt children? If q = 0.45, what fraction of a population are non-tasters?

10. **5 pts**

    A 6-mm circle on the tongue has 38 papillae. Find the density per cm^2.

11. **6 pts**

    Describe how taste typically changes from childhood to old age, and how a family can help a child learn to like a bitter vegetable.

12. **6 pts**

    Describe what Olds and Milner found and what dopamine signals, according to later research.

13. **6 pts**

    $L(x) = 9 - 0.08(x - 11)^2$. Find the bliss point, the maximum liking, and L(6).

14. **6 pts**

    Explain why a bowl of soup and a bag of chips with the same food energy affect fullness differently. Include energy density.

15. **18 pts**

    Short essay (6–8 sentences): A friend says, “I just can’t help eating a whole bag of chips; I must be addicted.” Respond kindly and accurately, using what you learned about the reward system, the bliss point, satiety signals and habits, and suggest two practical habits.

ANSWER KEY

1. Hänig (1901) found small regional differences; Boring (1942) redrew them as sharp zones and textbooks simplified them into the map. Swab tests and receptor studies show all five tastes are sensed all over the tongue.
2. Sweet: T1R2+T1R3. Umami: T1R1+T1R3. Bitter: about 25 T2R receptors. Salty: sodium ions through a channel. Sour: hydrogen ions (a proton channel).
3. 50 mL stock + 200 mL water; 0.05%.
4. In 1908 he isolated glutamate from kombu and named the taste umami; inosinate and guanylate.
5. 1.75; glutamate and guanylate bind the umami receptor together, so the combination is stronger than the sum.
6. A large family of odorant-receptor genes (1991); each odor activates a unique combination of receptors, read as a pattern by the brain.
7. $\binom{350}{3} = 7{,}084{,}700$
8. Most flavor is aroma reaching the nose from the mouth; a blocked nose stops it, leaving only the basic tastes.
9. ¼, ½, ¼; $q^2 = 0.20$.
10. $38 / 0.283 = 134$
11. Children are more bitter-sensitive and prefer sweet; tastes broaden with experience; smell and taste decline in old age. Offer small tastes repeatedly (often 8–15 times), prepare it in ways that reduce bitterness (roasting, salt, fat, acid), and never force or shame.
12. Animals would work to stimulate a brain area (the reward system); dopamine signals wanting and learning what predicts reward, not pleasure itself.
13. 11%, 9; $L(6) = 9 - 0.08(25) = 7.0$.
14. The soup has low energy density, with water, fiber and protein that stretch the stomach and trigger gut hormones; chips are energy-dense, eaten quickly, with little fiber or protein, so satiety signals are weaker.
15. Answers vary. Full credit for: describing dopamine as wanting/learning; explaining that some snacks are designed near bliss points with weak satiety signals, so it is easy to eat past full; noting it is not a drug addiction and habits can change (taste buds adjust in a few weeks); suggesting habits such as serving a portion in a bowl, eating slowly at the table, pairing snacks with fiber and protein, giving thanks; avoiding any body-size or shaming language.

UNIT PROJECT: THE FAMILY FLAVOR STUDY

Design and carry out a family flavor study with at least four tasters of different ages. Include three of these tests: a taste threshold test, a nose-pinched identification test, a papillae count, a bitter-vegetable comparison of two cooking methods, or an umami synergy test. Collect the data in tables, calculate averages, and graph the results.

Write a three-page report explaining the results with taste receptors, smell, genetics and age, and use what you learned to plan and cook one family dinner designed to please everyone at the table, with notes on how you balanced the five tastes and aroma. Present the report at the dinner, and begin with a word of thanks.

LOOK FOR	WHAT IT MEANS
Respect and safety	Allergies checked; tasters volunteered; no one pressured or teased about their tastes.
Data	Three tests carried out carefully with tables, averages and graphs.
Science explanation	Correct use of receptors, retronasal smell, genetics and age.
Applied cooking	A dinner thoughtfully balanced for the family, with notes.
Communication	Clear report and presentation.

9.1 Taste Receptors and the Tongue-Map Myth

OBJECTIVES

- Tell how a 1901 study by David Hänig was misread by Edwin Boring in 1942 into the "tongue map," and how taste receptors were finally identified around 2000.
- Explain how taste buds and receptor cells detect sweet, salty, sour, bitter and umami, and why every region of the tongue senses all five.
- Measure taste thresholds with a serial dilution, and balance a tomato soup by taste.

> **Warm-up.** Look in a mirror at your tongue. Find the small bumps (papillae). Dip a clean cotton swab in salt water and touch it to the tip, the sides and the back. Do you taste salt everywhere? (Check for allergies before any taste test; use only food-safe solutions and a fresh swab each time.)

WATCH

2-Minute Neuroscience: Taste

Neuroscientifically Challenged · 1:57

https://www.youtube.com/watch?v=wGXoYippog8

> **WHEN TO WATCH**
> During session 1. A quick, clear map of the path from a taste receptor to the brain; pause and copy each step.

BACKUP VIDEO

The Tongue Map is a Myth

University of Florida · 1:20

https://www.youtube.com/watch?v=leusvLYgkgc

Before the lab. A University of Florida taste scientist explains where the tongue map came from and why it is wrong.

KEY TERMS

papillae

The small bumps on the tongue. Fungiform, foliate and circumvallate papillae contain taste buds.

taste bud

A cluster of about 50–150 taste receptor cells with a pore that opens to the tongue's surface; adults have roughly 2,000–10,000.

taste receptor

A protein on a taste cell that responds to a taste molecule: T1R2+T1R3 for sweet, T1R1+T1R3 for umami, about 25 T2R types for bitter, and ion channels for salty and sour.

threshold

The lowest concentration at which a person can reliably detect a taste.

serial dilution

A series of solutions, each diluted by the same factor from the one before.

CORE IDEAS

The story. In 1901 the German scientist David Hänig carefully dripped solutions of sweet, salty, sour and bitter substances onto different spots around the edge of volunteers' tongues and found small differences in sensitivity from place to place. In 1942 the Harvard psychologist Edwin Boring, writing a history of the study of the senses, redrew Hänig's data in a way that made the small differences look like sharp zones. Textbooks then simplified his graph into the famous "tongue map," with sweet on the tip, bitter at the back and sour and salty on the sides.

How they figured it out. Anyone could have tested the map with a cotton swab and found that every taste is detected all over the tongue, and taste researchers such as Virginia Collings in 1974 showed experimentally that differences across the tongue are small. The full answer came from molecular biology. Between about 1999 and 2006, laboratories led by Charles Zuker and Nicholas Ryba, among others, identified the receptor proteins for sweet, umami and bitter, and showed that taste cells with each kind of receptor are found in taste buds all over the tongue. Each cell is tuned to one taste, but every region has all five kinds.

The kitchen science. Taste molecules dissolve in saliva, enter a taste bud's pore and meet receptors on the taste cells. **Sweet** (sugars) and **umami** (glutamate) are detected by paired receptor proteins; **bitter** by a family of about 25 receptor types, so we can sense many very different bitter compounds; **salty** mainly by sodium ions passing through a channel; and **sour** by hydrogen ions from acids. Taste cells pass signals to nerves that carry them to the brain. Taste cells wear out and are replaced every week or two. Taste is only part of flavor: most of what we call flavor is smell (Lesson 9.3), plus texture, temperature and the burn of chili or the cool of mint. Cooks balance taste: salt brightens and reduces bitterness, acid lifts flat food, sugar softens sourness and bitterness.

Let's cook. You will make a tomato soup and balance it with salt, acid and sweetness, one small addition at a time. The skill is **tasting and adjusting**, with a clean spoon each time.

PICTURE STUDY



Basket of Wild Strawberries, Jean-Siméon Chardin, 1761 · Oil on canvas · Private collection (exhibited at the Paris Salon of 1761)

Image: Wikimedia Commons, public domain

Chardin was famous in his own time for painting simple foods so that viewers felt they could almost taste them. Wild strawberries, tiny and intensely flavored, were a summer treasure.

Look closely

- Look at the strawberries. How has Chardin made them look juicy and ripe?
- Find the glass of water. Why might it be there?
- Find the peach and the cherries. Which tastes would each one give?
- Look at the shape of the pile. How did someone build it?

Talk about it

1. Strawberries taste sweet and slightly sour. Which receptors detect each of those tastes?
2. Much of a strawberry's flavor is aroma. What would it taste like if you held your nose?
3. Why do painters, poets and cooks all care about the taste of a strawberry? What does that say about the gift of the senses?

> **Safety first.** Check for allergies before any tasting. Use food-safe solutions only (sugar, salt, lemon juice), a fresh swab or spoon for every taste, and rinse your mouth with water between samples. The soup simmers hot: taste from a cooled spoonful.

KITCHEN LAB

Finding Your Taste Threshold

How weak can a sweet or salty solution be before you can no longer taste it, and does it matter where on the tongue you test? You will make serial dilutions, find your thresholds with a fair blind test, and test different tongue regions.

You will need

- A digital scale, measuring cups and a 100 mL measure
- Sugar and salt
- Twelve small clear cups and labels; cotton swabs
- A blindfold or helper to code the cups
- A pot and an immersion or regular blender (for the soup)
- Your lab notebook

Balanced Tomato Soup

Serves 6 · Prep 15 min · Cook 35 min

Ingredients

- 2 tablespoons olive oil and 1 tablespoon butter
- 1 large onion, chopped; 2 carrots, chopped; 3 cloves garlic, sliced
- 1 can (28 oz, 794 g) whole or crushed tomatoes
- 3 cups (720 mL) chicken or vegetable broth
- 1 teaspoon dried basil or a handful of fresh basil
- Salt, sugar and lemon juice or vinegar for balancing (see steps)
- ½ cup (120 mL) milk or cream (optional)

Method

1. Heat the oil and butter in a pot over medium heat. Cook the onion and carrots 8–10 minutes until soft; add the garlic for 1 minute.
2. Add the tomatoes, broth and basil. Bring to a boil, then simmer 20 minutes.

3. Let it cool 5 minutes, then blend until smooth (an immersion blender in the pot, or a regular blender filled no more than half full with the lid vented and covered with a towel).
4. **Balance:** taste a cooled spoonful. Add salt ¼ teaspoon at a time until the flavor "wakes up." If it tastes sharp or sour, add sugar ½ teaspoon at a time. If it tastes flat, add 1 teaspoon lemon juice. Taste after every addition with a clean spoon.
5. Stir in the milk if using and heat gently without boiling. Serve.
6. Wash the pot and blender; refrigerate leftovers within 2 hours.

Allergy check: Contains milk (butter, optional milk). Check broth labels. For milk-free, use all olive oil and skip the milk.

Steps

1. **Make dilutions.** Make 100 mL of 4% sugar solution and 100 mL of 1% salt solution. From each, make five two-fold dilutions (50 mL solution + 50 mL water each time).
2. **Code the cups.** Have a helper put a small sample of each solution and of plain water in coded cups so you do not know which is which.
3. **Test.** Starting with the weakest, taste each (sip and spit or swallow), rinse with water between, and say whether you taste anything and what. Record the lowest concentration you identify correctly. Repeat in a different random order.
4. **Regions.** With the 2% sugar and 0.5% salt, swab the tip, sides and back of the tongue and record whether you detect the taste at each.
5. **Compare** thresholds among family members.
6. **Cook** the soup and record each balancing addition and the effect.
7. **Conclusion.** Does your data support or refute the tongue map? Explain with taste receptors.
8. Clean up; discard all solutions.

Tips

- Rinse with plain water and wait 30 seconds between samples so taste does not carry over.

- Test at room temperature; very cold or hot samples are harder to taste.
- A little salt can make a soup seem less bitter and sweeter, not just saltier.

Check your work

- ☐ I can explain where the tongue map came from and why it is wrong.
- ☐ I can describe the receptors for the five basic tastes.
- ☐ I measured my taste thresholds with a serial dilution and balanced a soup by taste.

LAB NOTEBOOK

1. Draw a taste bud with receptor cells, the pore, and the nerve leaving it, labeling which receptors detect each taste.
2. Record your threshold data in a table and compare with family members.
3. Write the soup's balancing log: each addition and what it changed.

KEY FORMULAS

$$C_n = C_0 \times \left(\frac{1}{d}\right)^n$$

$$C_1 V_1 = C_2 V_2$$

From history. Aristotle listed sweet, bitter, salty and sour, with others such as astringent. Umami was added to the scientific list only after its receptor was found in the early 2000s (Lesson 9.2). Researchers continue to debate whether fat, starch or calcium might also have their own tastes.

WORKED EXAMPLES

Example 1. Starting with a 10% sugar solution, you make five two-fold dilutions. What is the concentration of each?

Show solution

1. Each step halves: $10\% \to 5\% \to 2.5\% \to 1.25\% \to 0.625\% \to 0.3125\%$.
2. $C_5 = 10\% \times \left(\tfrac{1}{2}\right)^5 = 0.31\%$.

Answer: 5%, 2.5%, 1.25%, 0.63% and 0.31%.

Example 2. How do you make 100 mL of 2.5% sugar solution from a 10% stock?

Show solution

1. $C_1V_1 = C_2V_2 \Rightarrow (10\%)V_1 = (2.5\%)(100\ \text{mL})$; $V_1 = 25\ \text{mL}$.

Answer: Mix 25 mL of the 10% stock with 75 mL of water.

Example 3. A student first reliably tastes salt in the 0.125% solution of a series from 1% downward by halves. Convert to grams of salt per liter and to millimoles per liter (NaCl 58.4 g/mol).

Show solution

1. $0.125\% = 1.25\ \text{g/L}$; $\dfrac{1.25\ \text{g}}{58.4\ \text{g/mol}} = 0.0214\ \text{mol} = 21\ \text{mmol/L}$.

Answer: About 1.25 g/L, or about 21 mmol/L, in the range typically reported for salt detection.

Example 4. If an adult has about 5,000 taste buds with about 100 receptor cells each, replaced on average every 10 days, how many taste cells are replaced each day?

Show solution

1. $\dfrac{5000 \times 100}{10\ \text{days}} = 50{,}000\ \text{cells/day}$.

Answer: About 50,000 taste cells a day, one reason tastes can adjust when eating habits change.

PRACTICE

1. Easy Name the five basic tastes.

   Show answer

   Sweet, salty, sour, bitter and umami.

2. Easy Who turned Hänig's data into the tongue map, and when?

   Show answer

   Edwin Boring, in 1942 (and later textbooks simplified it further).

3. Easy About how often are taste cells replaced?

Show answer

Every week or two (about 10 days on average).

4. Medium Why can humans detect many different bitter compounds?

Show answer

We have about 25 kinds of bitter receptors, each responding to different bitter molecules.

5. Medium Make 200 mL of 0.5% salt solution from a 2% stock.

Show answer

50 mL stock + 150 mL water.

6. Medium A 6% solution is diluted by halves four times. Find the final concentration.

Show answer

0.375%.

7. Medium What ions are detected as salty and as sour?

Show answer

Sodium ions (salty); hydrogen ions from acids (sour).

8. Medium Why does a bland soup often taste better after a pinch of salt and a squeeze of lemon?

Show answer

Salt enhances flavor and suppresses bitterness; acid adds brightness and balances richness.

9. Hard A student's threshold for sugar is 0.5% and a classmate's is 0.125%. How many two-fold dilutions apart are they, and who is more sensitive?

Show answer

Two dilutions; the classmate.

10. Hard Explain why the tongue map survived in textbooks for decades even though it could be disproved with a cotton swab.

Show answer

It was repeated from book to book without anyone checking the original data or testing it; a simple, memorable picture spread more easily than the careful truth.

11. Challenge Sour is detected through a proton channel (OTOP1, identified in 2018–2019). Explain why acids of the same pH can taste differently sour.

Show answer

Weak acids such as acetic acid can cross into taste cells as uncharged molecules and release H^+ inside, so sourness depends on the acid's identity and concentration, not only the solution's pH.

COMMON MISTAKES

- Believing the tongue map.
- Tasting samples in order from strongest to weakest, so the strong taste lingers.
- Adding salt or acid all at once instead of tasting in small steps.
- Using one spoon for tasting and stirring.

Make it a game · Tongue Map Myth Busters. Your parent reads five claims about the tongue map, such as bitter at the back and sweet at the tip. Correct each with the real facts about papillae, taste buds and receptors. Tell how Hänig's 1901 study was misread by Boring in 1942. Then explain a serial dilution and a taste threshold.

Scripture. "I will praise thee; for I am fearfully and wonderfully made: marvellous are thy works; and that my soul knoweth right well." (Psalm 139:14, KJV)

Fifty thousand new taste cells a day, five kinds of receptors on every part of the tongue: the more we learn about the senses, the more reason we have to praise their Maker.

9.2 Ikeda and Umami

OBJECTIVES

- Tell how Kikunae Ikeda isolated glutamate from kombu in Tokyo in 1908 and named the taste umami.
- Explain glutamate and the ribonucleotides (inosinate and guanylate), umami synergy, and the scientific consensus on the safety of glutamate.
- Run a blind tasting of kombu, shiitake and combined broths, and cook a dashi noodle soup.

> **Warm-up.** Taste (allergies permitting) a small piece of parmesan, a ripe tomato and a spoonful of broth. What do they have in common that is not sweet, salty, sour or bitter? Try to describe it in a few words.

WATCH

UMAMI: A Taste from Japan

Japan Video Topics - English · 4:12

https://www.youtube.com/watch?v=yP1RC_QMmsw

> **WHEN TO WATCH**
> During session 1. Note the foods rich in glutamate, and how Japanese chefs build umami in dashi.

KEY TERMS

umami

The savory, brothy "fifth taste," produced mainly by glutamate and boosted by inosinate and guanylate.

glutamate

The ionized form of glutamic acid, an amino acid. Free glutamate (not bound in protein) tastes umami.

MSG (monosodium glutamate)

The sodium salt of glutamic acid, a seasoning first made by Ikeda; chemically identical to the glutamate in tomatoes and cheese.

ribonucleotides

Inosinate (IMP, from meat and fish such as bonito) and guanylate (GMP, from dried mushrooms) that strongly enhance umami.

synergy

A combined effect greater than the sum of the separate effects. Glutamate with inosinate or guanylate tastes several times more umami than either alone.

dashi

Japanese stock made from kombu (kelp) and often bonito flakes or dried shiitake.

CORE IDEAS

The story. Kikunae Ikeda was a chemistry professor at Tokyo Imperial University. One evening, as the story is usually told, he noticed that his wife's *yudofu* (tofu simmered in kombu broth) had a delicious taste he could not describe as sweet, salty, sour or bitter. He set out to find its source. In 1908 he extracted the taste from large amounts of kombu seaweed and crystallized it: it was glutamic acid. He named the taste *umami*, from the Japanese word for delicious, and patented a method of making its sodium salt, which went on sale in 1909.

How they figured it out. Ikeda boiled and concentrated kombu broth, removed salts and other substances step by step, and tasted each fraction until he found the crystals that carried the taste. He also noticed that the same taste was in tomatoes, cheese, meat and asparagus. His student Shintaro Kodama found in 1913 that inosinate from dried bonito also tasted umami, and in 1957 Akira Kuninaka found guanylate in shiitake mushrooms and discovered that these compounds and glutamate strengthen each other. For decades Western scientists doubted umami was a basic taste, until the umami receptor (T1R1+T1R3) was identified in the early 2000s.

The kitchen science. Glutamate is one of the twenty amino acids. When it is bound in a protein it has no taste; when it is free, released by ripening, aging, drying, fermenting or long cooking, it tastes savory. That is why ripe tomatoes, aged parmesan, soy sauce, fish sauce, cured meats, mushrooms and long-simmered broths are rich in umami. Inosinate and guanylate bind to the same receptor at a different site and lock glutamate in place, so a broth of kombu (glutamate) and bonito or dried shiitake (inosinate or guanylate) tastes far more savory than either alone: **synergy**. Cooks all over the world use this pairing without naming it: tomato with meat, parmesan with mushrooms, soy sauce with fish. The glutamate in MSG is the same molecule as in a tomato; the FDA classifies MSG as generally recognized as safe, and controlled studies have not found that typical amounts cause the

symptoms once blamed on it, though anyone who reacts to a food should follow their doctor's advice.

Let's cook. You will make a kombu and shiitake dashi and turn it into a noodle soup with vegetables, tofu or chicken, and a soft-set egg cooked to 160 °F. The skill is **steeping, not boiling**: kombu is heated gently and removed before the water boils, so the broth stays clear and clean-tasting.

PICTURE STUDY



Mariko: Famous Tea Shop (from The Fifty-three Stations of the Tōkaidō), Utagawa Hiroshige, c. 1833–1834 · Woodblock print · The Metropolitan Museum of Art, New York

Image: Wikimedia Commons, public domain

Hiroshige's famous series showed the stations along the Tōkaidō road between Edo (Tokyo) and Kyoto. At Mariko, travelers stopped for the local specialty, *tororo-jiru*: grated mountain yam mixed into a savory broth and poured over rice.

Look closely

- Find the travelers. What are they eating?
- Find the woman serving them. What is she carrying on her back?
- Look at the shop's sign and roof. How can you tell this is a humble roadside place?
- What season do you think it is?

Talk about it

1. The tororo-jiru broth was likely flavored with dashi or miso. Which umami compounds would it contain?
2. Why might a savory, warm broth be especially welcome to a traveler on foot?
3. Hiroshige made an ordinary meal at a roadside shop a work of art. What ordinary meals in your life are worth remembering?

> **Safety first.** Check allergies before tasting (soy, wheat, fish and sesame are common in Japanese cooking). Cook any egg until the white is set and the yolk thickened (160 °F for a safe egg dish) or hard-cook it. The broth is very hot; ladle it carefully.

KITCHEN LAB

The Umami Synergy Test

Do glutamate and guanylate really strengthen each other? You will make three broths, kombu alone, dried shiitake alone and both together, and have family members rate them blind.

You will need

- Dried kombu (about 20 g) and dried shiitake mushrooms (about 15 g)
- Three small saucepans, a sieve and a digital scale
- Small coded tasting cups and clean spoons
- A large pot for the soup
- Your lab notebook

Kombu-Shiitake Dashi Noodle Soup

Serves 4 · Soak 30 min · Cook 25 min

Ingredients

- **Dashi:** 1.5 L (6⅓ cups) cold water, 20 g kombu, 15 g dried shiitake (about 6)
- 2 tablespoons soy sauce and 1 teaspoon sugar
- 8 oz (225 g) udon or ramen-style noodles
- 4 baby bok choy, halved, or 3 cups spinach
- 1 carrot, thinly sliced, and 3 green onions, sliced
- 7 oz (200 g) firm tofu, cubed, or 1½ cups cooked shredded chicken
- 4 large eggs (optional)
- Toasted sesame oil and sesame seeds for serving (optional)

Method

1. Soak the kombu and shiitake in the cold water in a pot for 30 minutes.
2. Heat slowly over medium-low. Just before it boils (small bubbles at the edge), remove the kombu. Simmer the shiitake 10 minutes more, then remove them, slice them thinly and set aside.

3. Season the dashi with soy sauce and sugar. Keep it hot.
4. Cook the noodles in a separate pot of boiling water according to the package; drain and rinse briefly.
5. If using eggs, simmer them in the noodle water 9–10 minutes (hard-cooked) and cool them in cold water; or poach them in the simmering broth until the whites are firm and the yolks have thickened.
6. Add the carrot and bok choy to the broth and simmer 2–3 minutes; add the tofu or chicken and heat through to 165 °F.
7. Divide the noodles among bowls, ladle in the broth and vegetables, add the sliced shiitake, halved eggs and green onions, and a few drops of sesame oil and seeds.
8. Wash the pots; refrigerate leftover broth within 2 hours.

Allergy check: Contains soy (soy sauce, tofu) and wheat (soy sauce, udon); eggs and sesame if used. For wheat-free, use tamari labeled gluten-free and rice noodles. Kombu and bonito-free dashi contains no fish; if you add bonito flakes, it contains fish.

Steps

1. **Hypothesis.** Predict the umami rating of each broth on a 0–10 scale.
2. **Make three test broths** in small pans, each with 500 mL water: (A) 7 g kombu, (B) 5 g shiitake, (C) 7 g kombu + 5 g shiitake. Soak and heat each the same way. Add the same pinch of salt to each.
3. **Code** the cups so tasters do not know which is which.
4. **Taste panel.** Three or more people rate each broth for umami (savory, brothy) from 0 to 10, rinsing with water between.
5. **Calculate** the average rating for each and the synergy factor.
6. **Cook** the noodle soup from the full dashi.
7. **Conclusion.** Was there synergy? Explain with glutamate, guanylate and the umami receptor.
8. Clean up.

Tips

- Do not wash the white powder off kombu; it is partly glutamate. Wipe it gently with a damp cloth if dusty.

- Boiling kombu makes the broth slimy and bitter; remove it before a full boil.
- Save the soaked shiitake for the soup; they are full of flavor.

Check your work

- ☐ I can tell how Ikeda discovered umami.
- ☐ I can explain glutamate, ribonucleotides and umami synergy, and what science says about MSG's safety.
- ☐ I tested umami synergy in a blind tasting and made dashi.

LAB NOTEBOOK

1. Draw the umami receptor with glutamate and guanylate bound together.
2. Record the taste-panel ratings in a table with averages and the synergy factor.
3. List ten umami-rich foods from different cuisines and how each is made rich in free glutamate (ripening, aging, fermenting, drying).

KEY FORMULAS

$$\text{concentration}\ (\text{mg/L}) = \frac{m\ (\text{mg})}{V\ (\text{L})}$$

$$\text{synergy factor} = \frac{\text{rating}\ (\text{combined})}{\text{rating}\ (\text{A}) + \text{rating}\ (\text{B})}$$

From history. Ikeda hoped his seasoning would make simple, nourishing food more appealing to Japanese families of modest means. Ajinomoto, the company that first produced it, today makes glutamate by fermentation of sugar beets, cane or corn with bacteria, much as yogurt or vinegar are made.

WORKED EXAMPLES

Example 1. Kombu contains roughly 1–3 g of free glutamate per 100 g. If 20 g of kombu releases 200 mg of glutamate into 1.5 L of water, what is the concentration in mg/L and in percent by mass?

Show solution

1. $\dfrac{200\ \text{mg}}{1.5\ \text{L}} = 133\ \text{mg/L}$.
2. $\dfrac{0.133\ \text{g}}{1000\ \text{g}} \times 100\% = 0.013\%$.

Answer: About 133 mg/L (0.013%). Umami is detectable at very low concentrations.

Example 2. In a tasting, the kombu broth gets an average umami rating of 2.0, the shiitake broth 1.5 and the combined broth 6.0. Find the synergy factor.

Show solution

1. $\dfrac{6.0}{2.0 + 1.5} = 1.7$.

Answer: 1.7: the combination tasted about 70% more umami than the two separate ratings added together.

Example 3. Glutamic acid has the formula $\text{C}_5\text{H}_9\text{NO}_4$. Find its molar mass, and the mass of glutamate in 0.010 mol.

Show solution

1. $5(12.01) + 9(1.008) + 14.01 + 4(16.00) = 147.1\ \text{g/mol}$.
2. $0.010 \times 147.1 = 1.47\ \text{g}$.

Answer: 147.1 g/mol; about 1.5 g.

Example 4. Parmesan contains about 1.2 g of free glutamate per 100 g. How much glutamate is in 30 g of grated parmesan, and how does it compare with 133 mg?

Show solution

1. $0.012 \times 30\text{ g} = 0.36\text{ g} = 360\text{ mg}$.

Answer: About 360 mg, nearly three times the glutamate in the whole pot of dashi, which is why a little parmesan adds so much savory taste.

PRACTICE

1. Easy What does umami mean, and who named it?

   Show answer

   "Delicious" or "savory taste"; Kikunae Ikeda, 1908.

2. Easy What molecule gives kombu its umami?

   Show answer

   Glutamate (from glutamic acid).

3. Easy Name a food rich in inosinate and one rich in guanylate.

   Show answer

   Inosinate: dried bonito, meat, fish. Guanylate: dried shiitake mushrooms.

4. Medium Why does bound glutamate in protein have no taste, while free glutamate does?

   Show answer

   The umami receptor responds to free glutamate molecules; glutamate locked in a protein chain cannot bind to it.

5. Medium Why are aged cheeses and ripe tomatoes richer in umami than fresh cheese and green tomatoes?

   Show answer

   Ripening and aging break down proteins, releasing free glutamate.

6. Medium Ratings: A 3.0, B 2.0, combined 8.0. Find the synergy factor.

   Show answer

   1.6.

7. **Medium** 300 mg of glutamate is dissolved in 2.0 L of broth. Find mg/L.

Show answer

150 mg/L.

8. **Medium** Is the glutamate in MSG different from the glutamate in tomatoes?

Show answer

No; it is the same molecule.

9. **Hard** Explain why tomato sauce with meat or parmesan on mushroom pasta tastes so satisfying, using umami synergy.

Show answer

Tomato and parmesan supply glutamate; meat (inosinate) or mushrooms (guanylate) supply ribonucleotides; together they activate the umami receptor much more strongly than either alone.

10. **Hard** Calculate the percent sodium by mass in monosodium glutamate, $C_5H_8NO_4Na$ (169.1 g/mol), and compare with table salt (39%).

Show answer

$22.99/169.1 = 13.6\%$ sodium, about a third of salt's.

11. **Challenge** Western scientists long doubted umami was a basic taste. What kind of evidence finally convinced them, and why was it decisive?

Show answer

The discovery of a specific receptor (T1R1+T1R3) and of nerve fibers that respond to glutamate; a dedicated receptor shows umami is detected as its own taste, not just as a combination of others.

COMMON MISTAKES

- Boiling kombu hard.
- Assuming umami is the same as salty.
- Thinking only Asian dishes have umami; parmesan, tomatoes and stock are full of it.
- Leaving eggs undercooked in soup.

> **Make it a game · Umami Stack Duel.** In two minutes each of you builds the most umami-rich three-ingredient combination from your pantry. Present it with glutamate and ribonucleotide synergy: for example kombu and dried mushroom in dashi. The parent judges by logic and scores. Tell how Ikeda isolated glutamate from kombu in Tokyo in 1908.

9.3 Smell and Flavor: Buck, Axel and the Receptor Genes

OBJECTIVES

- Tell how Linda Buck and Richard Axel discovered the large family of odorant-receptor genes in 1991 (Nobel Prize 2004).
- Explain orthonasal and retronasal smell, combinatorial coding of odors, and why most of flavor is smell.
- Run a blind identification test with and without the nose, and make a fresh herb pesto.

> **Warm-up.** Hold your nose and eat a jelly bean or a small piece of apple and then of raw potato (allergies permitting). Can you tell what it is? Let go of your nose halfway through chewing. What happens?

WATCH

Journey of Smell to the Brain

National Institutes of Health (NIH) · 3:05

https://www.youtube.com/watch?v=_Qyp157Az50

> **WHEN TO WATCH**
> During session 1. Trace the path of an odor molecule from the nose to the brain, and notice the role of smell in tasting food.

BACKUP VIDEO

Linda Buck, Nobel Prize in Physiology or Medicine 2004

Nobel Prize · 1:41

https://www.youtube.com/watch?v=BvV3vYsOzMk

After the story. A short interview with Linda Buck about the discovery that won the 2004 Nobel Prize.

KEY TERMS

olfaction

The sense of smell.

odorant receptor

A protein on olfactory neurons that binds odor molecules. Humans have about 400 working types, coded by a large family of genes.

combinatorial code

Each odor activates a particular combination of receptor types, and each receptor responds to several odors, so a few hundred receptors can distinguish an enormous number of smells.

orthonasal smell

Smelling through the nostrils, as when sniffing a rose.

retronasal smell

Smelling aromas that travel from the mouth up the back of the throat to the nose while chewing and swallowing; the main source of flavor.

flavor

The combined perception of taste, smell, texture, temperature and chemical sensations such as heat and cooling.

CORE IDEAS

The story. For most of history, how the nose could tell apart thousands of smells was a complete mystery. In the late 1980s Linda Buck, a young researcher in Richard Axel's laboratory at Columbia University, set out to find the receptors that odor molecules bind to. In 1991 Buck and Axel published their discovery: a huge family of about a thousand genes in rats, each coding for a different odorant receptor, active only in the nose's olfactory tissue. It was the largest gene family then known. They shared the Nobel Prize in Physiology or Medicine in 2004.

How they figured it out. Buck made three reasonable guesses to narrow her search: the receptors would belong to a known family of cell-surface receptors (G-protein-coupled receptors), they would form a large related family, and they would be active only in the olfactory tissue. Using a then-new method for copying DNA (PCR), she searched for genes matching all three and found them. Later work showed that each olfactory neuron makes just one kind of receptor and that neurons with the same

receptor all send their signals to the same spot in the brain's olfactory bulb, so each smell creates its own pattern there.

The kitchen science. Humans have about 400 working odorant receptor types (and many inactive genes). An odor activates a particular combination of receptors, and the brain reads the pattern, so combinations of a few hundred receptors can distinguish an enormous number of odors. While we eat, chewing releases aroma molecules that travel from the back of the mouth up into the nose: **retronasal smell**. The brain blends that with taste and feels it as coming from the mouth, which is why food tastes flat with a cold, and why most of what we call flavor is really smell. Cooks build aroma with fresh herbs, toasted spices, browned foods (Maillard and caramelization), citrus zest and garlic, and add delicate aromas at the end because heat drives volatile molecules off.

Let's cook. You will make a fresh basil pesto and serve it with pasta. Pesto is an aroma dish: its flavor comes from volatile compounds in raw basil and garlic. The skill is **protecting aroma**: not overheating the herbs, and adding the pesto off the heat.

PICTURE STUDY



Still Life with Apples and Oranges, Paul Cézanne, c. 1899 · Oil on canvas · Musée d'Orsay, Paris

Image: Wikimedia Commons, public domain

Cézanne painted apples and oranges again and again, studying their shapes and colors. Look long enough and you can almost smell the fruit.

Look closely

- Find the oranges and the apples. How does Cézanne make them look round and heavy?
- Look at the white cloth. How many colors can you find in the "white"?
- Find the pitcher. What might it hold?
- Imagine peeling one of these oranges. What would you smell first?

Talk about it

1. The smell of an orange comes mostly from oils in its peel. Why does grating zest into a recipe add so much flavor?
2. Why do you think the smell of certain foods can bring back strong memories?
3. How is looking closely at a painting like smelling or tasting closely?

Safety first. Check allergies before the blind test and the pesto: pine nuts are tree nuts, and parmesan is milk. Use a fresh spoon for each tasting. Wash basil well and dry it. Use a food processor with care: unplug it before reaching near the blade.

KITCHEN LAB

How Much of Flavor Is Smell?

How much harder is it to identify foods without the nose? You will run a blind test with the nose pinched and open, then make a pesto that depends on aroma.

You will need

- Six to eight small samples of different foods with similar texture (for example, flavored jelly beans, or grated apple, pear, potato and carrot)
- A blindfold and nose clip (or fingers)
- Cups of water for rinsing
- A food processor or mortar and pestle
- A large pot for pasta
- Your lab notebook

Basil Pesto Pasta

Serves 4–6 · Prep 15 min · Cook 12 min

Ingredients

- 60 g (about 2 packed cups) fresh basil leaves
- 30 g (¼ cup) pine nuts, lightly toasted (or sunflower seeds)
- 1 clove garlic
- 30 g (½ cup) finely grated parmesan
- 120 g (½ cup) extra-virgin olive oil
- ¼ teaspoon salt and 1 teaspoon lemon juice
- 1 lb (450 g) pasta such as fusilli or spaghetti
- Cherry tomatoes, halved, for serving (optional)

Method

1. Toast the pine nuts in a dry skillet over medium-low heat, stirring, 3–4 minutes until golden. Cool.
2. Pulse the basil, pine nuts and garlic in the food processor until finely chopped. With the machine running, pour in the oil. Add the parmesan,

salt and lemon juice and pulse briefly.

3. Cook the pasta in well-salted boiling water until al dente; save ½ cup of the cooking water before draining.
4. Off the heat, toss the hot pasta with the pesto and enough cooking water to make it creamy. Top with tomatoes.
5. Serve right away. Store leftover pesto with a thin layer of oil on top in the refrigerator up to 1 week.
6. Unplug the processor before removing the blade; wash it carefully.

Allergy check: Contains tree nuts (pine nuts), milk (parmesan) and wheat (pasta). For nut-free, use sunflower seeds; for milk-free, omit parmesan and add 2 tablespoons nutritional yeast or extra salt; for wheat-free, use gluten-free pasta.

Steps

1. **Hypothesis.** Predict your percent correct with the nose pinched and open.
2. **Prepare** samples in coded cups (a helper knows the code).
3. **Pinched round.** Blindfolded, with the nose pinched, taste each sample, rinse, and name it. Do not let go until you have answered.
4. **Open round.** Repeat in a new order with the nose open.
5. **Release test.** For two samples, pinch while chewing, then release and note the moment the flavor appears.
6. **Calculate** percent correct for each round and compare with the guessing level.
7. **Cook** the pesto pasta. Smell the basil raw, then smell the pesto on hot pasta. How does heat change the aroma?
8. **Conclusion.** Explain your results with retronasal smell and the combinatorial code.

Tips

- Pesto darkens as basil's compounds oxidize. A thin layer of oil on top slows it.
- Add pesto off the heat: cooking basil drives off its aroma molecules.
- When you have a cold, foods with strong taste (salt, acid) and texture are more satisfying, because smell is blocked.

Check your work

- ☐ I can tell how Buck and Axel discovered the odorant-receptor genes.
- ☐ I can explain retronasal smell and the combinatorial code.
- ☐ I measured how much smell contributes to identifying flavor and made a pesto that protects aroma.

LAB NOTEBOOK

1. Draw a side view of the head showing orthonasal and retronasal paths of aroma to the olfactory epithelium.
2. Record the blind-test results and graph percent correct for each round.
3. Make an “aroma map” of your pesto: which ingredient gives which smell?

KEY FORMULAS

$$\binom{n}{k} = \frac{n!}{k!\,(n-k)!}$$

$$\text{percent correct} = \frac{\text{correct}}{\text{trials}} \times 100\%$$

From history. Dogs have roughly twice as many working odorant-receptor genes as humans and far more olfactory tissue, which is why they are used to detect scents people cannot. Humans, though, are better at smelling than was once believed, and trained tasters can distinguish fine differences in aroma.

WORKED EXAMPLES

Example 1. If each odor activated exactly 3 of 400 receptor types, how many different 3-receptor combinations are possible?

Show solution

1. $\binom{400}{3} = \dfrac{400 \times 399 \times 398}{3 \times 2 \times 1} = 10{,}586{,}800.$

Answer: More than 10 million combinations from just triples; real odors activate varying numbers of receptors, giving far more.

Example 2. In a nose-pinched test, a taster identifies 3 of 12 flavors correctly; with the nose open, 11 of 12. Find both percentages. If there were 6 possible choices each time, what score would pure guessing give?

Show solution

1. Pinched: $\frac{3}{12} = 25\%$; open: $\frac{11}{12} = 92\%$.
2. Guessing: $\frac{1}{6} = 17\%$.

Answer: 25% with the nose pinched, barely above the 17% guessing level, and 92% with the nose open.

Example 3. A pesto uses 60 g basil, 30 g parmesan, 30 g pine nuts, 1 clove garlic (5 g) and 120 g olive oil. What percentage is oil, and what percentage is basil?

Show solution

1. Total: $60 + 30 + 30 + 5 + 120 = 245$ g.
2. Oil: $\frac{120}{245} = 49\%$; basil: $\frac{60}{245} = 24\%$.

Answer: About 49% oil and 24% basil. The oil carries the aroma molecules, which dissolve in fat.

PRACTICE

1. Easy Who discovered the odorant-receptor gene family, and when?

   Show answer

   Linda Buck and Richard Axel, 1991 (Nobel Prize 2004).

2. Easy About how many working odorant-receptor types do humans have?

   Show answer

   About 400.

3. Easy What is retronasal smell?

   Show answer

   Smelling aromas that travel from the mouth up the back of the throat to the nose during eating.

4. **Medium** Why does food taste bland when you have a stuffy nose?

Show answer

Aroma molecules cannot reach the olfactory receptors, and most flavor is retronasal smell.

5. **Medium** How many combinations of 2 receptors can be made from 400 types?

Show answer

$\binom{400}{2} = 79{,}800$

6. **Medium** Why add fresh herbs and citrus zest at the end of cooking?

Show answer

Their aroma molecules are volatile and evaporate with long heating.

7. **Medium** A taster gets 4 of 10 correct pinched and 9 of 10 open. Find each percent.

Show answer

40% and 90%.

8. **Medium** Why does pesto use oil rather than water?

Show answer

Many aroma molecules dissolve in fat, so the oil captures and carries them.

9. **Hard** Explain how a few hundred receptor types can distinguish many thousands of odors.

Show answer

Each odor activates a unique combination of receptors and each receptor responds to several odors; the brain reads the pattern, and the number of possible patterns is enormous.

10. **Hard** What three guesses did Linda Buck use to narrow her search for the receptor genes?

Show answer

They would be G-protein-coupled receptors, they would form a large related gene family, and they would be expressed only in olfactory tissue.

11. **Challenge** A vanilla ice cream and a vanilla-scented candle smell similar but one tastes sweet. Explain why the brain experiences the ice cream's vanilla as a "taste."

    Show answer

    In the mouth, the vanilla aroma reaches the nose retronasally at the same time sweet receptors on the tongue fire; the brain combines them into one flavor perceived in the mouth.

COMMON MISTAKES

- Saying something "tastes like" strawberry, when really it smells like strawberry.
- Cooking delicate herbs for a long time.
- Forgetting to check for nut allergies before making pesto.
- Reaching into a food processor while it is plugged in.

Make it a game · How Much Is Smell. Pour three different juices into cups. With your nose pinched, taste a sip of each blind and guess; then repeat with your nose open. Record the percent right each way. Explain orthonasal and retronasal smell and the combinatorial code. Tell how Buck and Axel found odorant-receptor genes in 1991.

Scripture. "O taste and see that the LORD is good: blessed is the man that trusteth in him." (Psalm 34:8, KJV)

The psalmist uses the most personal of the senses to invite us to know God's goodness by experience, not only by hearing about it.

9.4 Genetics of Taste: Fox's PTC and Bartoshuk's Supertasters

OBJECTIVES

- Tell how Arthur Fox discovered in 1931 that some people taste PTC as bitter and others taste nothing, and how Linda Bartoshuk identified "supertasters" in the 1990s.
- Explain how a gene (TAS2R38) affects bitter taste, use a Punnett square and allele frequencies, and describe how taste changes from childhood to old age.
- Count fungiform papillae, and cook Brussels sprouts two ways to compare bitterness.

> **Warm-up.** Ask everyone in your family how they feel about broccoli, Brussels sprouts, grapefruit and dark chocolate. Make a quick table. Do some people dislike all the bitter foods? Do any run in the family?

WATCH

Are You A Supertaster | Test Your Tongue

ABC Science · 2:23

https://www.youtube.com/watch?v=jExqPBLgf-o

> **WHEN TO WATCH**
> During session 1. Watch how the presenter counts papillae with blue food coloring; you will do the same in the lab.

BACKUP VIDEO

Do you have the bitter taste gene? | Science-U

wpsu · 1:33

https://www.youtube.com/watch?v=fqVSNiWDTQU

After the story. Students test whether they carry the bitter-taste gene with PTC strips.

KEY TERMS

PTC (phenylthiocarbamide)

A chemical that tastes intensely bitter to some people and has no taste to others; used to study taste genetics.

TAS2R38

A bitter-taste receptor gene; common variants explain most of the difference in PTC tasting.

allele

One version of a gene. Each person has two alleles of most genes, one from each parent.

supertaster

A person who tastes bitterness (and often other tastes) much more intensely than average, often with more fungiform papillae.

fungiform papillae

Mushroom-shaped bumps on the front of the tongue that hold taste buds; they stain lighter when the tongue is dyed blue.

Hardy–Weinberg

A simple model relating allele frequencies (p and q) to genotype frequencies (p^2, 2pq, q^2) in a population.

CORE IDEAS

The story. In 1931 Arthur Fox, a chemist at the DuPont company, was pouring a fine powder of phenylthiocarbamide (PTC) into a bottle when some of it blew into the air. A colleague nearby, C. R. Noller, complained of a bitter taste. Fox, who was much closer to the dust, tasted nothing at all. Curious, Fox tested friends and family and found that people fell into two groups: tasters and non-tasters. In the 1990s, the Yale and later University of Florida taste scientist Linda Bartoshuk found that among tasters, some people experience bitterness far more intensely than others. She called them **supertasters**.

How they figured it out. Geneticists quickly saw that PTC tasting ran in families, and by the 1930s it was being used as a classic example of an inherited trait. In 2003 a research team led by Dennis Drayna identified the gene, TAS2R38, a bitter receptor: people with two copies of the “non-taster” version cannot taste PTC. Bartoshuk measured how intensely people rated tastes and counted the fungiform papillae on their tongues, and found that supertasters tend to have more of them. Studies estimate that roughly a quarter of people are non-tasters of PTC, about half are

medium tasters and about a quarter are supertasters, though the proportions vary among populations.

The kitchen science. Bitter compounds in vegetables of the cabbage family (such as glucosinolates in broccoli and Brussels sprouts) resemble PTC, so people with sensitive versions of TAS2R38 often find these vegetables more bitter. Taste also changes with age: children are more sensitive to bitterness and prefer sweeter foods than adults, which may help protect them from eating harmful things; tastes broaden with experience, and people often need many tastes of a new food (8 to 15 is a common estimate) before they like it; in later life, smell and to a lesser extent taste gradually decline. None of this is fixed fate: cooking changes bitterness. Roasting browns sugars (Maillard and caramelization) that mask bitterness; salt suppresses bitter perception; fat and sweet-acid sauces balance it. Modern Brussels sprouts are also milder than older varieties because plant breeders in the 1990s selected varieties with less of the bitter compounds.

Let's cook. You will cook Brussels sprouts two ways, boiled and roasted with a honey-lemon glaze, and have tasters rate their bitterness. The skill is **using cooking to balance bitterness**.

PICTURE STUDY



Gregor Mendel, Unknown photographer, c. 1862 · Photograph · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Gregor Mendel (1822–1884) was an Augustinian friar in Brno (now in the Czech Republic). By breeding garden peas in his monastery garden from 1856 to 1863, he discovered the basic laws of inheritance that explain traits like PTC tasting.

Look closely

- Look at his clothing. What does it tell you about his life?
- Look at his spectacles and steady gaze. What kind of careful work would he do in his garden?
- Look at his face. Does he seem patient? Why would patience matter in his work?

Talk about it

1. Mendel studied peas, a food plant, in a monastery garden. How did ordinary work with food lead to a great discovery?
2. Mendel's laws were ignored until 1900. Why might a discovery be overlooked?
3. How does Mendel's work help explain why some people in a family find broccoli bitter and others do not?

> **Safety first.** Do not use PTC strips without a parent's approval; some families prefer to skip them. Use only food coloring for the papilla test, with a clean swab. Roasting is at 425 °F: use mitts. Check allergies (honey is never given to babies under one year).

KITCHEN LAB

Tongues, Genes and Brussels Sprouts

You will count fungiform papillae on willing family members, gather a family bitterness survey, and compare boiled and roasted Brussels sprouts in a blind taste panel.

You will need

- Blue food coloring and cotton swabs
- A paper hole punch and a small piece of wax paper or a reinforcement ring (to make a 6-mm window)
- A magnifying glass and a flashlight
- Optional: PTC test strips (with parent approval)
- A pot, a sheet pan and mitts
- Your lab notebook

Roasted Brussels Sprouts with Honey-Lemon Glaze

Serves 4–6 · Prep 15 min · Roast 25 min

Ingredients

- 1½ lb (680 g) Brussels sprouts, trimmed and halved
- 3 tablespoons olive oil
- ¾ teaspoon salt and ¼ teaspoon pepper
- 1 tablespoon honey (or maple syrup)
- 1 tablespoon lemon juice and 1 teaspoon grated zest
- 2 tablespoons grated parmesan (optional)

Method

1. Heat the oven to 425 °F (220 °C). Set aside a handful of sprouts for the boiled comparison.
2. Toss the rest with the oil, salt and pepper and spread them cut side down on a sheet pan.
3. Roast 20–25 minutes, until the cut sides are deeply browned and the sprouts are tender.

4. Meanwhile, boil the reserved sprouts in salted water 6–8 minutes until tender; drain.
5. Whisk the honey, lemon juice and zest and toss with the roasted sprouts. Sprinkle with parmesan.
6. Serve. Wash the pan and pot.

Allergy check: Contains milk if parmesan is used. Honey is never given to babies under one year.

Steps

1. **Survey.** Ask family members to rate their liking of five bitter foods (1–5) and record any family patterns.
2. **Papillae count (volunteers only).** Dab blue food coloring on the tip of the tongue with a swab. Place the 6-mm window on the tongue tip and count the pink, unstained bumps with the magnifier. Calculate density.
3. **Optional PTC test** with parent approval: classify each person as non-taster, taster or strong taster.
4. **Taste panel.** Serve boiled and roasted sprouts in coded cups; tasters rate bitterness and liking (0–10).
5. **Analyze.** Find means; compare papillae counts with bitterness ratings. Is there a pattern?
6. **Ages.** If you have family members of different ages, compare their ratings and discuss how taste changes over a lifetime.
7. **Conclusion.** Explain your results with TAS2R38, papillae and the chemistry of roasting.
8. Clean up.

Tips

- Small samples are enough; be sensitive to family members who dislike a food and do not pressure anyone.
- Count papillae quickly before the dye fades, or take a photograph and count on the screen.
- If someone dislikes Brussels sprouts, try again in a few weeks in a different preparation; liking often grows with repeated tastes.

Check your work

- ☐ I can explain how Fox and Bartoshuk discovered differences in bitter taste.
- ☐ I can use a Punnett square and allele frequencies to predict taster types.
- ☐ I measured papillae and compared cooking methods in a blind panel.

LAB NOTEBOOK

1. Draw a Punnett square for two Tt parents and label each outcome as taster or non-taster.
2. Record the papillae counts and the family survey in tables.
3. Write a plan to help a younger child learn to enjoy a bitter vegetable over several weeks.

KEY FORMULAS

$$p + q = 1 \qquad p^2 + 2pq + q^2 = 1$$

$$\text{papillae density} = \frac{\text{count}}{\pi r^2}$$

From history. Mendel's laws were rediscovered in 1900 by three botanists working independently. PTC tasting became one of the first human traits used in classrooms to teach Mendelian genetics, though scientists now know that bitter taste is shaped by several genes and by experience.

WORKED EXAMPLES

Example 1. Let T be the taster allele and t the non-taster allele. Two parents are both Tt. Use a Punnett square to find the chance that a child is a non-taster (tt).

Show solution

1. Outcomes: TT, Tt, tT, tt, each with probability ¼.
2. Non-taster: tt, $\frac{1}{4} = 25\%$.

Answer: 25%. Three out of four children would be tasters (TT or Tt).

Example 2. If the non-taster allele t has frequency q = 0.5 in a population, what fraction of people are non-tasters, and what fraction carry at least one T?

Show solution

1. $q^2 = 0.25$; $1 - q^2 = 0.75$.

Answer: About 25% non-tasters and 75% tasters, close to many measured populations.

Example 3. A student counts 30 fungiform papillae in a 6-mm-diameter circle on the tongue tip. Find the density per cm².

Show solution

1. Radius 0.30 cm; area $\pi(0.30)^2 = 0.283$ cm^2.
2. $\dfrac{30}{0.283} = 106$ papillae/cm^2.

Answer: About 106 papillae per cm². Bartoshuk's studies found much higher counts in many supertasters.

Example 4. A family of 6 rates boiled Brussels sprouts 7, 8, 5, 9, 6, 7 for bitterness (0–10) and roasted ones 4, 5, 2, 6, 3, 4. Find the means and the percent reduction.

Show solution

1. Boiled: $\dfrac{42}{6} = 7.0$; roasted: $\dfrac{24}{6} = 4.0$.
2. $\dfrac{7.0 - 4.0}{7.0} \times 100\% = 43\%$.

Answer: Means 7.0 and 4.0; roasting reduced perceived bitterness about 43%.

PRACTICE

1. Easy What did Arthur Fox notice in 1931?

Show answer

His colleague tasted bitter PTC dust in the air while Fox tasted nothing.

2. Easy What gene explains most PTC tasting differences?

Show answer

TAS2R38.

3. Easy Who coined the term “supertaster”?

Show answer

Linda Bartoshuk.

4. Medium Parents Tt and tt. What fraction of children would be non-tasters?

Show answer

½.

5. Medium If q = 0.6 for the non-taster allele, what fraction are non-tasters?

Show answer

$q^2 = 0.36$

6. Medium Why do roasted Brussels sprouts taste less bitter than boiled ones?

Show answer

Browning creates sweet and savory compounds that mask bitterness, and caramelized sugars balance it.

7. Medium How does taste typically change from childhood to old age?

Show answer

Children are more sensitive to bitter and prefer sweet; tastes broaden with experience; in old age smell (and somewhat taste) decline.

8. Medium About how many tastes of a new food do people often need before liking it?

Show answer

Often about 8 to 15.

9. Hard A student counts 45 papillae in a 6-mm circle. Find the density.

Show answer

$45 / 0.283 = 159$ per cm^2

10. Hard In a population, 30% are non-tasters. Estimate q and p, and the fraction of heterozygotes (Tt).

Show answer

$q = \sqrt{0.30} = 0.55$, $p = 0.45$; $2pq = 0.49$.

11. Challenge Why might sensitivity to bitterness have been useful, and why does it not have to keep someone from enjoying vegetables?

Show answer

Many poisonous plants are bitter, so sensitivity helped people avoid harmful foods. Cooking methods (roasting, salt, fat, acid, sweetness) and repeated tasting reduce perceived bitterness and build liking.

COMMON MISTAKES

- Assuming a child who dislikes a vegetable will never like it.
- Boiling cabbage-family vegetables too long, which releases more sulfur and bitter compounds.
- Treating taste differences as a matter of good or bad character rather than biology and experience.
- Forgetting that most “taste” differences also involve smell.

> **Make it a game · Allele Arithmetic.** Your parent says 25 percent of a group cannot taste PTC. Use Hardy–Weinberg to find q, p, and the percent who carry one copy of the allele. Do four different group percentages, racing the clock. Explain TAS2R38 and supertasters with Bartoshuk. Tell how Arthur Fox discovered PTC differences in 1931.

9.5 Reward, Cravings and Satiety: Olds, Milner and the Bliss Point

OBJECTIVES

- Tell how James Olds and Peter Milner found the brain's reward pathway in 1954, and how Howard Moskowitz searched for the "bliss point" of sweetness.
- Explain dopamine as a signal of wanting and learning, why combinations of sugar, salt and fat are easy to overeat, and the body's satiety signals.
- Run a satiety comparison and cook a hearty lentil soup; model a bliss point with a quadratic function.

> **Warm-up.** Think of a food you sometimes keep eating even after you are no longer hungry. What is it like (sweet, salty, crunchy, rich)? Now think of a meal that left you satisfied for hours. What was in it? Write both down without judging yourself.

WATCH

Reward pathway in the brain | Processing the Environment | MCAT | Khan Academy

khanacademymedicine · 8:26

https://www.youtube.com/watch?v=YzCYuKX6zp8

> **WHEN TO WATCH**
> During session 1. Follow the path of the reward pathway on the diagram, and note which brain areas the presenter names.

KEY TERMS

reward system

Brain circuits, including dopamine neurons in the midbrain and their targets such as the nucleus accumbens, that help us learn what is worth seeking.

dopamine

A messenger chemical in the brain linked to wanting, motivation and learning what predicts something good; it is not simply "pleasure."

satiety

The feeling of fullness and satisfaction that lasts after a meal.

satiety signals

Messages to the brain that we have eaten enough: stomach stretch and hormones such as CCK and PYY from the gut; they take about 20 minutes to build.

bliss point

The concentration of an ingredient (such as sugar) at which people's liking peaks; above it, liking falls.

energy density

Food energy per gram (kcal/g). Foods with water and fiber (soups, vegetables) have low energy density.

CORE IDEAS

The story. In 1954 James Olds and Peter Milner, two young researchers at McGill University in Montreal, were studying how stimulating part of a rat's brain affected learning. One electrode was slightly off target. To their surprise, the rat kept returning to the corner of its cage where it had received the stimulation, and when the animals were allowed to press a lever to stimulate that spot themselves, they pressed it again and again. They had found what came to be called the brain's reward system. Decades later, the food-industry researcher Howard Moskowitz became known for testing many versions of a product, from soft drinks to pasta sauces, to find the sweetness or saltiness at which liking peaks: the "bliss point."

How they figured it out. Later neuroscientists, including Kent Berridge, showed that the dopamine signal in this system is mostly about *wanting* and *learning*: it rises when we expect something good and teaches us to seek it again, which is different from the enjoyment of eating itself. Moskowitz's method was statistical: give many people many versions and plot liking against the amount of an ingredient. Liking typically rises, peaks and falls: the bliss point.

The kitchen science. God made us able to enjoy sweet, salty and rich foods, which in nature signal energy, minerals and nourishment. The brain learns to want foods that deliver them. Some packaged snack foods are designed to combine sugar, salt, fat and crunch near their bliss points, with little fiber or protein, so that they are very easy to keep eating past full; they melt quickly and give few satiety signals. Fullness comes from several signals that build over about 20 minutes: the stomach stretching, hormones like CCK and PYY released as food reaches the intestine, and

slower signals over hours. Foods with **fiber, protein and water**, such as soups, beans, vegetables, whole grains, eggs and fruit, give strong satiety signals for their energy. Tastes are not fixed: when people eat less added sugar or salt for a few weeks, their taste buds adjust and the same foods taste sweeter or saltier. Treats and feasts are good gifts in their place; self-control, the fruit of the Spirit, helps us enjoy them without letting them rule us.

Let's cook. You will cook a hearty lentil and vegetable soup, rich in fiber, protein and water, and run a simple satiety comparison. The skill is **building a satisfying meal**.

PICTURE STUDY



Saying Grace before the Barbecue Dinner at the Pie Town Fair, Russell Lee, for the Farm Security Administration, October 1940 · Photograph · Library of Congress, Washington, D.C.

Image: Wikimedia Commons, public domain

At the Pie Town fair in 1940, the homesteading community shared a free barbecue dinner. Russell Lee photographed the moment before the meal, when everyone bowed to give thanks.

Look closely

- Look at the people's heads and hands. What are they doing?
- Find the men holding their hats. Why would they take them off?
- Look at the clothing and the setting. What was life like for these families?
- Find the children. How are they taking part?

Talk about it

1. How does pausing to give thanks change the way we eat a meal?
2. These families worked hard for their food. How might that shape the way they enjoyed a feast?
3. Sharing a meal slowly with others gives the body time to feel satisfied. What else does a shared meal give us?

> **Safety first.** Check allergies before the satiety comparison. Lentils must be rinsed and picked over for small stones. The soup simmers for 30 minutes; stir with a long spoon and ladle carefully. This lab compares how foods satisfy; it is not a reason to skip meals or eat less than you need.

KITCHEN LAB

What Keeps Us Satisfied?

Which afternoon snack keeps you satisfied longer: one rich in fiber and protein, or one that is mostly refined starch? On two different days, with the same lunch, you will eat a snack of about the same food energy and record your fullness over time. Then you will cook a satisfying lentil soup.

You will need

- Two snacks of about the same food energy (about 200 kcal each, from the labels): for example, an apple with 2 tablespoons of peanut butter, and about 50 g of pretzels
- A timer and a fullness scale (0 = very hungry, 10 = very full)
- A large pot for the soup
- Your lab notebook

Hearty Lentil and Vegetable Soup

Serves 6–8 · Prep 15 min · Cook 40 min

Ingredients

- 2 tablespoons olive oil
- 1 onion, 2 carrots and 2 celery ribs, diced
- 3 cloves garlic, minced
- 1 teaspoon ground cumin, 1 teaspoon smoked paprika, ½ teaspoon dried thyme
- 1½ cups (300 g) brown or green lentils, rinsed and picked over
- 1 can (14.5 oz) diced tomatoes
- 7 cups (1.7 L) vegetable or chicken broth
- 1 teaspoon salt (adjust to taste) and ½ teaspoon pepper
- 3 cups chopped spinach or kale, and 1–2 tablespoons lemon juice

Method

1. Heat the oil in a large pot over medium heat. Cook the onion, carrots and celery 8 minutes; add the garlic and spices for 1 minute.

2. Add the lentils, tomatoes, broth, salt and pepper. Bring to a boil, then simmer partly covered 25–30 minutes, until the lentils are tender.
3. Stir in the greens for 2–3 minutes and the lemon juice. Taste and adjust the salt.
4. Serve with whole-grain bread. Cool leftovers quickly and refrigerate (they keep 4–5 days) or freeze.
5. Wash the pot and board.

Allergy check: Contains celery (a common allergen in some countries). Check broth labels. Serve with bread containing wheat or a gluten-free alternative. If using the peanut butter snack in the lab, it contains peanuts; use sunflower-seed butter instead if needed.

Steps

1. **Plan** two afternoons with the same lunch and activity. Choose two snacks with about the same food energy from their labels.
2. **Hypothesis.** Predict which snack will keep you satisfied longer, and why.
3. **Day 1.** Eat snack A at a set time, slowly. Rate fullness at 0, 30, 60, 90 and 120 minutes, and note the time you first feel hungry.
4. **Day 2.** Repeat with snack B.
5. **Graph** fullness against time for both snacks. Compare their fiber and protein from the labels.
6. **Cook** the lentil soup for a family dinner. Calculate the fiber and protein per serving from your ingredients' labels.
7. **Bliss point model.** Using Worked Example 1, sketch L(x) and explain what happens to liking above and below the bliss point.
8. **Conclusion.** Explain your results with satiety signals, fiber, protein and water. Write one habit your family could adopt to enjoy food and feel satisfied.

Tips

- Keep everything else the same on both days: sleep, lunch, activity and drinks.
- Rate honestly; there are no right answers in a fullness scale.
- A squeeze of lemon at the end brightens lentil soup without more salt.

Check your work

- ☐ I can explain dopamine as wanting and learning, and the satiety signals.
- ☐ I can explain why some snack foods are easy to overeat and others satisfy.
- ☐ I ran a satiety comparison, modeled a bliss point and cooked a satisfying soup.

LAB NOTEBOOK

1. Draw the reward pathway from the midbrain to the nucleus accumbens and label dopamine's role.
2. Graph your fullness ratings for both snacks.
3. Write the lentil soup recipe with fiber and protein per serving.

KEY FORMULAS

$$L(x) = L_{\max} - a\,(x - x_0)^2$$

$$\text{energy density} = \frac{\text{kcal}}{\text{grams of food}}$$

From history. Moskowitz's work showed that there is often not one perfect product but several groups of people with different preferences; this led companies to offer several versions (mild, spicy, chunky) of the same food. The idea that variety in a meal increases how much we eat is called sensory-specific satiety: we tire of one taste faster than of a varied meal.

WORKED EXAMPLES

Example 1. A taste panel's liking of a lemonade is modeled by L(x) = 8 − 0.05(x − 10)^2, where x is the sugar percentage. Find the bliss point, the maximum liking, and the liking at 4% and at 16% sugar.

Show solution

1. The vertex is at $x_0 = 10\%$, with $L_{\max} = 8$.
2. $L(4) = 8 - 0.05(36) = 6.2$; $L(16) = 8 - 0.05(36) = 6.2$.

Answer: Bliss point 10% sugar, liking 8; both 4% and 16% give 6.2. Liking falls off on both sides of the peak.

Example 2. A bowl of lentil soup (400 g) provides about 280 kcal of food energy; a 50-g bag of chips provides about 270 kcal. Compare their energy densities.

Show solution

1. Soup: $\frac{280}{400} = 0.70$ kcal/g. Chips: $\frac{270}{50} = 5.4$ kcal/g.

Answer: The soup has about one-eighth the energy density: for similar energy, you eat eight times the volume, with fiber, protein and water that signal fullness. (Calories here are simply a unit of food energy.)

Example 3. If a person's satiety signals take about 20 minutes to build, and they eat at a pace of 1 bite every 6 seconds, how many bites could they eat before the signals catch up?

Show solution

1. $\frac{20 \times 60 \text{ s}}{6 \text{ s/bite}} = 200$ bites.

Answer: About 200 bites. Eating slowly, talking at the table and serving a portion on a plate give the body time to respond.

Example 4. A sauce has 12 g of added sugar per ½-cup serving. How many teaspoons is that (4 g per teaspoon), and what fraction of the 50-g Daily Value?

Show solution

1. $\frac{12}{4} = 3$ tsp; $\frac{12}{50} = 24\%$.

Answer: 3 teaspoons, 24% of the Daily Value for added sugars.

PRACTICE

1. Easy What did Olds and Milner discover in 1954?

   Show answer

   A brain area (part of the reward system) whose stimulation animals would work to receive.

2. Easy Is dopamine best described as “pleasure” or as “wanting and learning”?

Show answer

Wanting and learning what is worth seeking.

3. Easy About how long do satiety signals take to build?

Show answer

About 20 minutes.

4. Medium Name three food components that help us feel satisfied.

Show answer

Fiber, protein and water.

5. Medium $L(x) = 7 - 0.1(x - 12)^2$. Find the bliss point and maximum liking.

Show answer

12%, liking 7.

6. Medium Find L(8) and L(16) for problem 5.

Show answer

Both 5.4.

7. Medium Find the energy density of 300 g of vegetable soup with 150 kcal.

Show answer

0.5 kcal/g.

8. Medium Why can packaged snacks that combine sugar, salt, fat and crunch be easy to overeat?

Show answer

They hit near the bliss point for several tastes, melt quickly, and have little fiber or protein, so they give weak satiety signals while the reward system learns to want them.

9. Hard A cereal has 16 g of added sugar per serving. Convert to teaspoons and %DV (50 g).

Show answer

4 tsp; 32%.

10. Hard Explain how taste buds can adjust when a family uses less added sugar for a few weeks.

Show answer

Taste cells are replaced every week or two and the brain adapts to the usual level, so after a few weeks less sugar tastes sweet enough and very sweet foods may taste too sweet.

11. Challenge Why is it more accurate to say that some foods are “designed to be easy to overeat” than that they are “addictive like a drug”?

Show answer

The reward system responds to food as it should, by learning to want it; food design can exploit that learning, but food does not act on the brain the way addictive drugs do, and people can retrain habits and enjoy such foods in their place.

COMMON MISTAKES

- Calling foods “good” or “bad”; describe what a food does, not the person eating it.
- Eating straight from a large bag instead of serving a portion.
- Eating so fast that satiety signals have no time to work.
- Skipping meals, which makes cravings stronger later.

Make it a game · Satiety Swap. Your parent names a snack, such as a sugary cereal. You have sixty seconds to make it more satisfying using fiber, protein, water or lower energy density, while keeping it appealing. Present your swap and defend it. Also correct this myth: dopamine does not equal pleasure. Tell the story of Olds, Milner and the bliss point.

Scripture. “But the fruit of the Spirit is love, joy, peace, longsuffering, gentleness, goodness, faith, Meekness, temperance: against such there is no law.” (Galatians 5:22-23, KJV)

Temperance (self-control) is listed among the fruit of the Spirit alongside joy. Enjoying good food with thanks and with self-control belong together.

UNIT 9

Taste, Smell and the Brain

Why does food taste good? This unit follows a bite of food from the tongue and nose to the brain. You will learn how taste receptors detect the five basic tastes, how Ikeda found the fifth, how smell creates most of what we call flavor, why people differ in how they taste bitterness, and how the brain's reward system and the body's fullness signals shape what and how much we want to eat.

The stories follow the tongue-map mistake and the discovery of taste receptors, Kikunae Ikeda's kombu broth, Linda Buck and Richard Axel's receptor genes, Arthur Fox's PTC dust and Linda Bartoshuk's supertasters, and Olds, Milner and the bliss point. The labs measure taste thresholds, umami synergy, smell's share of flavor, papillae and bitterness, and satiety. The recipes are a balanced tomato soup, dashi noodle soup, basil pesto pasta, roasted Brussels sprouts and a hearty lentil soup. Throughout, we talk about food as a good gift, enjoyed with thanks and self-control, never in terms of body size.

PREREQUISITES

- Unit 4: amino acids (for glutamate)
- Unit 3: sugars and fiber
- Basic probability, square roots and quadratic functions (vertex form)

MASTERY CHECKLIST

- ☐ I can describe taste buds and the receptors for the five basic tastes, and explain why the tongue map is a myth.
- ☐ I can explain umami, glutamate, ribonucleotides and synergy.
- ☐ I can explain retronasal smell and the combinatorial code of odor receptors.
- ☐ I can explain taste genetics with a Punnett square and allele frequencies, and how taste changes with age.
- ☐ I can explain dopamine as wanting, the bliss point and satiety signals, with no body-size talk.
- ☐ I can calculate dilutions, combinations, densities, energy density and a quadratic bliss point.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **Monell Chemical Senses Center**: Free articles and videos from a research institute devoted to taste and smell.
- **Blue food coloring and a small magnifying glass**: For the papillae count in Lesson 9.4.
- **PTC or thiourea taste strips**: Optional, with a parent's approval; inexpensive from science-education suppliers. The lab works without them.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

9.1 Taste Receptors and the Tongue-Map Myth — 3 sessions of 50–90 minutes

9.2	**Ikeda and Umami**	3 sessions of 50–90 minutes
9.3	**Smell and Flavor: Buck, Axel and the Receptor Genes**	3 sessions of 50–90 minutes
9.4	**Genetics of Taste: Fox's PTC and Bartoshuk's Supertasters**	3 sessions of 50–90 minutes
9.5	**Reward, Cravings and Satiety: Olds, Milner and the Bliss Point**	3 sessions of 50–90 minutes

Unit 9 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   Explain how the tongue map arose and what the evidence shows instead.

2. **6 pts**
   Name the receptor or mechanism for each of the five basic tastes.

3. **6 pts**
   How do you make 250 mL of a 0.4% salt solution from a 2% stock? What is the concentration after three more two-fold dilutions?

4. **6 pts**
   Describe Ikeda's discovery and name the two compounds that strengthen umami.

5. **6 pts**
   Ratings: kombu 2.5, shiitake 1.5, combined 7.0. Find the synergy factor and explain the result.

6. **6 pts**

   What did Buck and Axel discover, and how does a few hundred receptors code thousands of odors?

7. **5 pts**

   How many combinations of 3 receptors can be made from 350 types?

8. **6 pts**

   Explain why food tastes bland with a cold, using retronasal smell.

9. **6 pts**

   Two parents are Tt for the taster gene. What are the chances of TT, Tt and tt children? If q = 0.45, what fraction of a population are non-tasters?

10. **5 pts**

    A 6-mm circle on the tongue has 38 papillae. Find the density per cm^2.

11. **6 pts**

    Describe how taste typically changes from childhood to old age, and how a family can help a child learn to like a bitter vegetable.

12. **6 pts**

    Describe what Olds and Milner found and what dopamine signals, according to later research.

13. **6 pts**

    $L(x) = 9 - 0.08(x - 11)^2$. Find the bliss point, the maximum liking, and L(6).

14. **6 pts**

    Explain why a bowl of soup and a bag of chips with the same food energy affect fullness differently. Include energy density.

15. **18 pts**

    Short essay (6–8 sentences): A friend says, “I just can’t help eating a whole bag of chips; I must be addicted.” Respond kindly and accurately, using what you learned about the reward system, the bliss point, satiety signals and habits, and suggest two practical habits.

ANSWER KEY

1. Hänig (1901) found small regional differences; Boring (1942) redrew them as sharp zones and textbooks simplified them into the map. Swab tests and receptor studies show all five tastes are sensed all over the tongue.
2. Sweet: T1R2+T1R3. Umami: T1R1+T1R3. Bitter: about 25 T2R receptors. Salty: sodium ions through a channel. Sour: hydrogen ions (a proton channel).
3. 50 mL stock + 200 mL water; 0.05%.
4. In 1908 he isolated glutamate from kombu and named the taste umami; inosinate and guanylate.
5. 1.75; glutamate and guanylate bind the umami receptor together, so the combination is stronger than the sum.
6. A large family of odorant-receptor genes (1991); each odor activates a unique combination of receptors, read as a pattern by the brain.
7. $\binom{350}{3} = 7{,}084{,}700$
8. Most flavor is aroma reaching the nose from the mouth; a blocked nose stops it, leaving only the basic tastes.
9. ¼, ½, ¼; $q^2 = 0.20$.
10. $38 / 0.283 = 134$
11. Children are more bitter-sensitive and prefer sweet; tastes broaden with experience; smell and taste decline in old age. Offer small tastes repeatedly (often 8–15 times), prepare it in ways that reduce bitterness (roasting, salt, fat, acid), and never force or shame.
12. Animals would work to stimulate a brain area (the reward system); dopamine signals wanting and learning what predicts reward, not pleasure itself.
13. 11%, 9; $L(6) = 9 - 0.08(25) = 7.0$.
14. The soup has low energy density, with water, fiber and protein that stretch the stomach and trigger gut hormones; chips are energy-dense, eaten quickly, with little fiber or protein, so satiety signals are weaker.
15. Answers vary. Full credit for: describing dopamine as wanting/learning; explaining that some snacks are designed near bliss points with weak satiety signals, so it is easy to eat past full; noting it is not a drug addiction and habits can change (taste buds adjust in a few weeks); suggesting habits such as serving a portion in a bowl, eating slowly at the table, pairing snacks with fiber and protein, giving thanks; avoiding any body-size or shaming language.

UNIT PROJECT: THE FAMILY FLAVOR STUDY

Design and carry out a family flavor study with at least four tasters of different ages. Include three of these tests: a taste threshold test, a nose-pinched identification test, a papillae count, a bitter-vegetable comparison of two cooking methods, or an umami synergy test. Collect the data in tables, calculate averages, and graph the results.

Write a three-page report explaining the results with taste receptors, smell, genetics and age, and use what you learned to plan and cook one family dinner designed to please everyone at the table, with notes on how you balanced the five tastes and aroma. Present the report at the dinner, and begin with a word of thanks.

LOOK FOR	WHAT IT MEANS
Respect and safety	Allergies checked; tasters volunteered; no one pressured or teased about their tastes.
Data	Three tests carried out carefully with tables, averages and graphs.
Science explanation	Correct use of receptors, retronasal smell, genetics and age.
Applied cooking	A dinner thoughtfully balanced for the family, with notes.
Communication	Clear report and presentation.

UNIT 10

Nutrition Science and Food Technology

The final unit connects the chemistry and biology of food to the people who eat it and the technology that brings it to them. You will learn how food energy was measured, how vitamins were discovered, how to read the Nutrition Facts label and the Dietary Guidelines, how food additives are regulated, and how food technology from freeze-drying to extrusion fed astronauts on the way to the Moon. We treat food energy as a unit of measurement only, never something to restrict, and we weigh claims about food by evidence, not fear.

The stories follow Wilbur Atwater's calorimeter, Eijkman's chickens, Funk's "vitamine" and McCollum's vitamin A, the people who designed the Nutrition Facts label, Harvey Wiley's Poison Squad and Rita Rapp's Apollo food. The recipes are chicken burrito bowls, a rainbow vegetable stir-fry, chewy granola bars, a bright fruit salad and crunchy roasted chickpeas. The unit and the course end with your capstone: an original food-science experiment you design, carry out and present.

PREREQUISITES

- Units 1–9, especially experimental design (Unit 1), water and heat (Unit 2), carbohydrates and fiber (Unit 3) and preservation (Unit 8)
- Percentages, ratios, unit conversions and graphing
- A parent's approval for the capstone plan

MASTERY CHECKLIST

- ☐ I can explain how food energy is measured and calculate it with the Atwater factors, as energy only.
- ☐ I can explain the discovery of vitamins, water- and fat-soluble vitamins, and cooking that protects them.
- ☐ I can read a Nutrition Facts label, calculate %DV and teaspoons of added sugar, and write a panel for a recipe.
- ☐ I can explain what food additives do and how they are regulated (GRAS, the 1906 and 1958 laws), using evidence.
- ☐ I can explain freeze-drying and extrusion, and calculate moisture and rehydration ratios.
- ☐ I designed, ran and presented an original food-science experiment.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FDA: How to Understand and Use the Nutrition Facts Label**: Free. The FDA's own guide to every line of the label, for Lesson 10.3.
- **USDA FoodData Central**: Free online at fdc.nal.usda.gov. Nutrient data for thousands of foods, for the nutrient tables in Lessons 10.1 and 10.3.
- **Povidone-iodine and cornstarch**: For the vitamin C test in Lesson 10.2; inexpensive from a pharmacy and grocery store. The lesson can be done as a demonstration video instead.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

10.1 Atwater's Calorimeter: Measuring Food Energy	3 sessions of 50–90 minutes
10.2 The Vitamins: Funk, McCollum and Vitamin C	3 sessions of 50–90 minutes
10.3 The Nutrition Facts Label and the Dietary Guidelines	3 sessions of 50–90 minutes
10.4 Food Additives and GRAS: Harvey Wiley's Poison Squad	3 sessions of 50–90 minutes
10.5 Food Technology and the Capstone: Freeze-Dried Space Food	3 sessions of 50–90 minutes (plus the capstone project over 2–3 weeks)

Unit 10 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   Describe Atwater's respiration calorimeter and what it showed.

2. **7 pts**
   A meal contains 85 g carbohydrate, 40 g protein and 22 g fat. Find its food energy and the percentage from fat.

3. **5 pts**
   A bomb calorimeter's 2,500 g of water warms 1.6 °C from burning 1.0 g of a food. Find kcal/g.

4. **6 pts**
   Explain the difference between water-soluble and fat-soluble vitamins, with two examples of each and one cooking consequence.

5. **6 pts**

   Tell how Eijkman, Funk and McCollum each contributed to the discovery of vitamins.

6. **5 pts**

   Fresh juice needs 18 drops and boiled juice 30 drops to clear the iodine–starch indicator. Find the percent of vitamin C retained.

7. **7 pts**

   A snack label: serving 40 g, 180 kcal, fiber 3 g, added sugars 14 g, sodium 210 mg. Find the teaspoons of added sugar and the %DV for fiber (28 g), added sugars (50 g) and sodium (2,300 mg).

8. **5 pts**

   A package holds 3.5 servings at 140 kcal each. If you eat half the package, how much food energy is that?

9. **6 pts**

   What did the 2016 label update change, and why?

10. **6 pts**

    Describe Wiley’s Poison Squad and the two laws that followed (1906 and 1958).

11. **5 pts**

    How does ascorbic acid prevent browning, and how does lemon juice help?

12. **5 pts**

    Find the ppm of 0.15 g of an additive in 1.2 kg of food.

13. **6 pts**

    Explain freeze-drying and why the food rehydrates quickly.

14. **7 pts**

    800 g of peaches (88% water) are freeze-dried to 3% moisture. Find the dried mass and the energy to sublimate the ice (2,830 J/g).

15. **18 pts**

Short essay (7–9 sentences): Describe your capstone experiment as a scientist would in a short report: the question, hypothesis, variables, method and safety plan, results with numbers, conclusion, sources of error, and one idea for a follow-up experiment. Name at least two units of this course that your experiment drew on.

ANSWER KEY

1. A sealed, insulated chamber where a person lived for days while heat, oxygen and carbon dioxide were measured; it showed energy is conserved in the body and gave the 4-4-9 factors.
2. $340 + 160 + 198 = 698$ kcal; fat 28%.
3. 4.0 kcal/g.
4. Water-soluble (C, B vitamins) dissolve in water and are lost in cooking water and heat; fat-soluble (A, D, E, K) dissolve in fat, are more stable and are absorbed better with fat.
5. Eijkman linked polished rice to a beriberi-like disease in chickens (1890s); Funk proposed "vitamines" for deficiency diseases (1912); McCollum and Davis found fat-soluble A (1913).
6. 60%.
7. 3.5 tsp; fiber 11%, added sugars 28%, sodium 9%.
8. 245 kcal.
9. Added sugars line, realistic serving sizes, larger food-energy type, vitamin D and potassium; based on newer science and on what people actually eat.
10. Volunteers ate measured preservatives under observation (1902–07); the 1906 Pure Food and Drug Act; the 1958 Food Additives Amendment required pre-approval of new additives and created GRAS.
11. Ascorbic acid is an antioxidant that reverses browning intermediates; lemon juice's acid lowers pH and slows the enzyme (and supplies vitamin C).
12. 125 ppm.
13. Food is frozen, then ice sublimates under vacuum with gentle heat; the ice leaves without melting, leaving a porous structure that absorbs water quickly.
14. Solids 96 g; dried 99 g; ice removed 701 g; $q = 1.98 \times 10^6$ J.
15. Answers vary. Full credit for a complete, honest summary with a testable question, clear variables, replicated trials, numerical results, a conclusion supported by the data, specific errors, a sensible follow-up, a safety plan, and connections to two units.

UNIT PROJECT: THE CAPSTONE REPORT AND PRESENTATION

Complete the capstone begun in Lesson 10.5: an original food-science experiment drawing on at least two units of this course. Submit a written report in the form of a short scientific paper (title, abstract, introduction with a historical story, methods with safety plan, results with tables and graphs, discussion, conclusion and references) of 4–6 pages.

Present your work to your family or a small audience in a 5–8 minute talk or poster, and serve a dish connected to your experiment, beginning with a word of thanks. Keep the report with your lab notebook as the record of a full year of laboratory food science.

LOOK FOR	WHAT IT MEANS
Question and design	A focused, testable question; one independent variable; controls; at least three trials per treatment; parent-approved safety plan.
Data and analysis	Honest, complete data with units; correct calculations; clear graphs.
Science	Results explained correctly with concepts from at least two units.
Report	Well-organized scientific paper with a historical introduction and references.
Presentation and hospitality	Clear, confident talk or poster; a dish served with thanks.

10.1 Atwater's Calorimeter: Measuring Food Energy

OBJECTIVES

- Tell how Wilbur Atwater measured the energy in foods and in human metabolism with his respiration calorimeter in the 1890s, and gave us the 4-4-9 factors.
- Distinguish carbohydrates, proteins, fats, vitamins and minerals, and calculate the food energy of a recipe from its macronutrients, as a unit of energy only.
- Cook chicken burrito bowls and build a nutrient table for one serving.

> **Warm-up.** A food label says 200 Calories. What do you think that number measures? Write your best guess, and then think about how anyone could possibly measure the energy in a slice of bread.

WATCH

Let's Learn Food Science - Atwater Factors for Determining Calories

Amy Proulx · 16:09

https://www.youtube.com/watch?v=tc8mddI-b8Y

> **WHEN TO WATCH**
> During session 1. A college food-science instructor explains Atwater's method, the calorie as a unit of heat, and proximate analysis; take notes on the Atwater factors.

Note: A slide lecture from a food-science professor's small channel, chosen because it teaches Atwater's method at the right level. Calories in this course are a unit of food energy, never something to count or restrict.

KEY TERMS

macronutrients

Carbohydrates, proteins and fats: nutrients needed in large amounts that supply energy and building materials.

micronutrients

Vitamins and minerals, needed in small amounts and supplying no energy themselves.

calorie and Calorie

A calorie (small c) heats 1 g of water by 1 °C (4.184 J). The food Calorie (capital C, or kcal) is 1,000 of these.

Atwater factors

Average energy available from food: about 4 kcal per gram of carbohydrate or protein and 9 kcal per gram of fat.

calorimeter

An instrument that measures heat. A bomb calorimeter burns food in oxygen; Atwater's respiration calorimeter measured the heat given off by a person.

CORE IDEAS

The story. Wilbur Olin Atwater, a chemistry professor at Wesleyan University in Connecticut, was concerned in the 1880s and 1890s with a practical question: how could working families get the most nourishment for their money? To answer it he needed to know how much energy different foods actually supplied. With the physicist Edward Rosa he built a room-sized respiration calorimeter, completed in 1896, in which a volunteer lived for several days at a time, eating measured meals, while instruments measured the heat his body gave off, the oxygen used and the carbon dioxide produced.

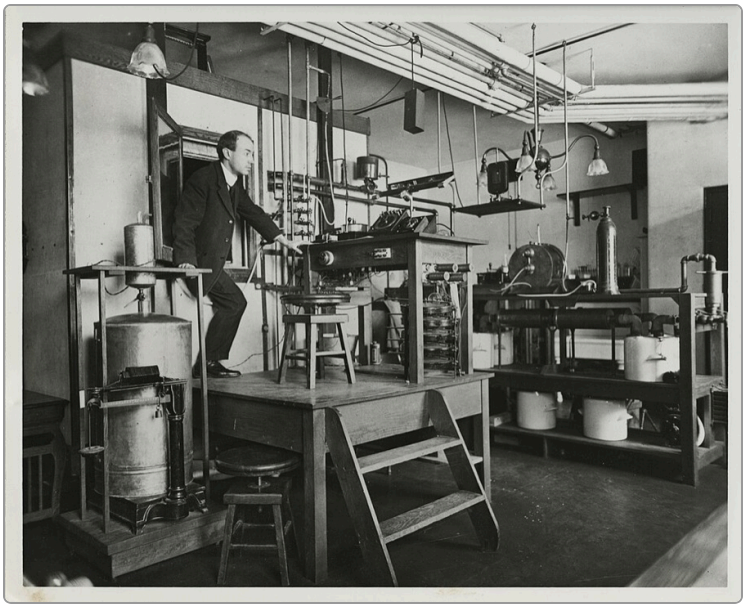
How they figured it out. Atwater burned samples of foods in a bomb calorimeter to measure their total energy, then measured what the body actually used, subtracting the energy lost in digestion and waste. His careful bookkeeping showed that the first law of thermodynamics, conservation of energy, holds for the human body just as for a steam engine: energy taken in balances energy given off and stored. From thousands of measurements he arrived at the average factors still used on food labels today: about 4 kcal per gram of carbohydrate, 4 per gram of protein and 9 per gram of fat. He also published tables of food composition that the USDA used for decades.

The kitchen science. The body uses the **macronutrients** for energy and for building: carbohydrates (sugars and starches) are the main fuel, especially for the brain and active muscles; proteins supply amino acids to build and repair tissues; fats supply energy, essential fatty acids and help absorb vitamins A, D, E and K. **Micronutrients**, vitamins and minerals, supply no energy but are essential in small amounts (Lesson

10.2). Water is essential too. Fat is energy-dense because its molecules are mostly carbon and hydrogen, which release more energy when oxidized than the partly oxidized carbohydrates. Growing teenagers need plenty of food energy and a wide variety of nutrient-dense foods. In this course we calculate energy as a scientist does, to understand food, never to restrict or to judge.

Let's cook. You will cook chicken burrito bowls, a meal that brings together carbohydrates, protein, fats, vegetables and flavor, and make a nutrient table for one bowl. The skill is **building a balanced bowl.**

PICTURE STUDY



Atwater's Respiration Calorimeter, Unknown photographer, c. 1900 · Photograph · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

A volunteer lived inside this insulated chamber for days at a time, eating, sleeping, reading and exercising, while Atwater's team measured every bit of heat, oxygen and carbon dioxide.

Look closely

- Find the window. Why would the scientists need to see inside?
- Find the pipes and gauges. What do you think they measured?
- Imagine living in the chamber for several days. How would food be passed in?
- Find the man on the platform. What kind of patience would this work need?

Talk about it

1. Atwater wanted to help working families get the most nourishment for their money. How is measuring food energy useful for that?
2. Why is it important to remember that a food's value is more than its energy?
3. What did Atwater's experiments show about energy in the human body?

> **Safety first.** Cook chicken to 165 °F (74 °C) and use separate boards for raw chicken and vegetables. Rice should be cooled quickly and refrigerated within 2 hours. Check every topping against your family's allergies.

KITCHEN LAB

A Nutrient Table for a Real Meal

You will cook burrito bowls and, using the Nutrition Facts labels of your ingredients (or the USDA FoodData Central database), calculate the macronutrients and food energy in one serving.

You will need

- A digital scale and measuring cups
- The Nutrition Facts labels of your ingredients, or access to USDA FoodData Central
- A medium saucepan with lid, a large skillet and a thermometer
- Two cutting boards
- A calculator or spreadsheet
- Your lab notebook

Chicken Burrito Bowls

Serves 6 · Prep 25 min · Cook 30 min

Ingredients

- 1½ cups (285 g) long-grain white or brown rice, cooked with a squeeze of lime and chopped cilantro
- 1½ lb (680 g) boneless chicken thighs or breasts
- 1 tablespoon oil, 2 teaspoons chili powder, 1 teaspoon cumin, ½ teaspoon garlic powder, 1 teaspoon salt
- 2 cans (15 oz each) black beans, drained, rinsed and warmed with ½ teaspoon cumin
- 1½ cups corn kernels (frozen is fine), sautéed or warmed
- Toppings: salsa, chopped lettuce, sliced avocado, shredded cheese, plain yogurt or sour cream, lime wedges

Method

1. Cook the rice. Season the chicken with the spices and salt.

2. Heat the oil in the skillet over medium-high heat and cook the chicken 5–7 minutes per side until it reaches 165 °F (74 °C). Rest 5 minutes and slice.
3. Warm the beans and corn.
4. Build bowls: rice, beans, corn, chicken, and toppings. Weigh one complete bowl for your nutrient table.
5. Refrigerate leftovers in separate containers within 2 hours.
6. Wash the raw-chicken board and sanitize it.

Allergy check: Contains milk (cheese, yogurt or sour cream). Check salsa and spice labels. For milk-free, skip the dairy toppings.

Steps

1. **Plan.** Make a table with a row for each ingredient in one bowl: mass, carbohydrate, protein, fat and fiber (g).
2. **Measure.** Weigh each component as you build one bowl.
3. **Look up** the nutrients per 100 g or per serving from labels or FoodData Central and scale them to your masses.
4. **Calculate** total carbohydrate, protein, fat and fiber, food energy by the Atwater factors, and the percentage of energy from each macronutrient.
5. **Compare** the percentages with the Dietary Guidelines ranges for teenagers (carbohydrate 45–65%, protein 10–30%, fat 25–35%).
6. **Variation.** Suggest one change that would add more fiber or vegetables and recalculate.
7. **Conclusion.** Explain the Atwater factors and what the numbers do and do not tell you about a meal's value.
8. Clean up.

Tips

- Most labels round values; small differences from your calculation are normal.
- Weigh cooked rice and beans, and use nutrient values for the cooked food.
- A spreadsheet makes scaling and adding many ingredients fast.

Check your work

- ☐ I can tell how Atwater measured food energy and explain the 4-4-9 factors.
- ☐ I can calculate food energy and macronutrient percentages.
- ☐ I built a nutrient table for a real meal I cooked.

LAB NOTEBOOK

1. Draw Atwater's calorimeter in cross-section with arrows for heat, oxygen and carbon dioxide.
2. Paste your nutrient table and a pie chart of energy from each macronutrient.
3. Write two sentences on what a nutrient table does not tell you about a meal (taste, fellowship, vitamins, variety).

KEY FORMULAS

$$E = 4m_{\text{carb}} + 4m_{\text{protein}} + 9m_{\text{fat}} \quad (\text{kcal, masses in g})$$

$$1\ \text{kcal} = 4.184\ \text{kJ}$$

From history. Atwater's food-composition tables (1896) were the first major American tables of their kind; the USDA's modern FoodData Central database is their descendant. He also helped found the system of agricultural experiment stations in the United States.

WORKED EXAMPLES

Example 1. One bowl contains 70 g carbohydrate, 35 g protein and 18 g fat. Find its food energy in kcal and kJ, and the percentage from each macronutrient.

Show solution

1. $E = 4(70) + 4(35) + 9(18) = 280 + 140 + 162 = 582$ kcal.
2. $582 \times 4.184 = 2435$ kJ.
3. Carbohydrate $\dfrac{280}{582} = 48\%$; protein 24%; fat 28%.

Answer: About 580 kcal (2.4 MJ): 48% from carbohydrate, 24% protein, 28% fat, close to the ranges in the Dietary Guidelines.

Example 2. A bomb calorimeter burns 1.00 g of dry rice. The 2,000 g of water around it warms by 1.87 °C. Find the energy released in kcal.

Show solution

1. $q = (2000)(1)(1.87)\ \text{cal} = 3740\ \text{cal} = 3.74\ \text{kcal}$.

Answer: About 3.7 kcal per gram, close to the 4 kcal/g Atwater factor (the body cannot use quite all of it).

Example 3. How many minutes could the 582 kcal in the bowl power a 100-W light bulb?

Show solution

1. $582\ \text{kcal} \times 4184\ \tfrac{\text{J}}{\text{kcal}} = 2.44 \times 10^{6}\ \text{J}$.
2. $t = \dfrac{2.44 \times 10^{6}\ \text{J}}{100\ \text{W}} = 24{,}400\ \text{s} \approx 6.8\ \text{h}$.

Answer: About 6.8 hours: food contains a great deal of energy. The resting human body uses energy at roughly the rate of a 100-W bulb.

PRACTICE

1. Easy What are the Atwater factors?

   Show answer

   About 4 kcal/g carbohydrate, 4 kcal/g protein, 9 kcal/g fat.

2. Easy Convert 250 kcal to kJ.

   Show answer

   1,046 kJ.

3. Easy Name the three macronutrients and one job of each.

   Show answer

   Carbohydrate (energy), protein (building and repair), fat (energy, essential fatty acids, absorbing fat-soluble vitamins).

4. **Medium** Find the energy of a snack with 30 g carbohydrate, 8 g protein and 10 g fat.

Show answer

$120 + 32 + 90 = 242$ kcal

5. **Medium** In problem 4, what percentage of the energy comes from fat?

Show answer

$90/242 = 37\%$

6. **Medium** Why does fat provide more than twice the energy per gram of carbohydrate?

Show answer

Fat molecules are mostly carbon and hydrogen (less oxidized), so oxidizing them releases more energy.

7. **Medium** What did Atwater's experiments show about energy in the body?

Show answer

Energy is conserved: energy from food equals the energy given off as heat and work plus energy stored.

8. **Medium** A bomb calorimeter's 1,500 g of water warms 2.4 °C when 1.0 g of cracker burns. Find kcal/g.

Show answer

3.6 kcal/g

9. **Hard** Why are food-label Calories somewhat less than the energy measured by burning food in a bomb calorimeter?

Show answer

Not all food is digested and absorbed, and protein's nitrogen leaves the body in urea, which still contains energy.

10. **Hard** A recipe makes 6 bowls with a total of 420 g carbohydrate, 210 g protein, 108 g fat. Find energy per bowl.

Show answer

$(1680 + 840 + 972)/6 = 582$ kcal

11. **Challenge** Atwater's goal was to help families of modest means. Using cost per gram of protein, compare dried beans ($1.60 per lb, 22% protein dry) and chicken ($3.50 per lb, 20% protein raw).

    Show answer

    Beans: 454 × 0.22 = 100 g protein per $1.60 → 1.6¢/g. Chicken: 91 g per $3.50 → 3.8¢/g. Beans supply protein at less than half the cost.

COMMON MISTAKES

- Treating food energy as a score of good or bad.
- Forgetting to scale label values to the actual amount eaten.
- Mixing up kcal (food Calories) and kJ.
- Ignoring fiber, vitamins and minerals, which supply no energy but matter greatly.

Make it a game · Reverse Atwater. Your parent gives a food's total energy, such as 300 Calories, plus grams of carbohydrate and protein. Use 4, 4 and 9 to find the grams of fat. Race a timer for six puzzles. Distinguish calorie from Calorie in one sentence. Tell how Atwater's respiration calorimeter measured energy in food and in the human body.

Scripture. "Whether therefore ye eat, or drink, or whatsoever ye do, do all to the glory of God." (1 Corinthians 10:31, KJV)

Eating is not only fuel and numbers. It is part of a life lived with thanks to God.

10.2 The Vitamins: Funk, McCollum and Vitamin C

OBJECTIVES

- Tell how Christiaan Eijkman, Casimir Funk (who coined “vitamine” in 1912) and Elmer McCollum (vitamin A, 1913) discovered that foods contain essential trace nutrients.
- Distinguish water-soluble and fat-soluble vitamins, explain how cooking affects them, and calculate percent Daily Value.
- Compare vitamin C in raw and cooked juice with an iodine–starch test, and cook a colorful vegetable stir-fry.

> **Warm-up.** Look at the most colorful foods in your kitchen. Make a list of their colors. Do you think the colors have anything to do with nutrients? Guess which vitamins might be in an orange carrot and a green leaf.

WATCH

The Chemist Who Discovered Vitamins

Rational Thinker · 7:33

https://www.youtube.com/watch?v=sPRS0vlpAVs

> **WHEN TO WATCH**
> During session 1. Note each scientist’s experiment and what disease it explained.

BACKUP VIDEO

Introduction to vitamins and minerals | Biology foundations | High school biology | Khan Academy

Khan Academy · 6:11

https://www.youtube.com/watch?v=TBNCqRCsSvY

During the reading. A clear explanation of water-soluble and fat-soluble vitamins and what they do in the body.

KEY TERMS

vitamin

An organic compound the body needs in small amounts but cannot make in sufficient amounts, so it must come from food.

fat-soluble vitamins

Vitamins A, D, E and K; they dissolve in fat, are absorbed with dietary fat and are stored in the body.

% Daily Value

The percentage of a day's reference amount of a nutrient supplied by one serving; for vitamin C the Daily Value is 90 mg.

water-soluble vitamins

Vitamin C and the B vitamins; they dissolve in water, are easily lost in cooking water, and are not stored in large amounts.

deficiency disease

Illness caused by lack of a nutrient, such as scurvy (vitamin C), beriberi (thiamin, B_1), rickets (vitamin D) and night blindness (vitamin A).

CORE IDEAS

The story. In the 1890s the Dutch physician Christiaan Eijkman, working in Java, noticed that chickens fed polished white rice developed a paralysis like the human disease beriberi, while chickens fed unpolished brown rice did not. In 1912 the Polish-born biochemist Casimir Funk, working in London, proposed that beriberi, scurvy, pellagra and rickets were each caused by the lack of a particular substance in food, which he called a *vitamine* (a "vital amine"). In 1913, at the University of Wisconsin, Elmer McCollum and Marguerite Davis found a growth factor dissolved in butterfat and egg yolk but not in lard: "fat-soluble A," later vitamin A.

How they figured it out. These scientists used controlled feeding experiments, often with laboratory animals, giving purified diets that differed in only one food and watching for disease. When it turned out that not all of these substances were amines, the final "e" was dropped, giving "vitamin." Vitamin C was isolated by Albert Szent-Györgyi in the late 1920s and early 1930s, and its structure soon determined, finally explaining Lind's citrus (Lesson 1.5). Eijkman and Frederick Hopkins shared the 1929 Nobel Prize for the discovery of vitamins.

The kitchen science. Vitamins are needed in milligrams or micrograms, but without them the body cannot carry out essential chemistry. Water-soluble vitamins (C and the B group) leach into cooking water and are damaged by heat, air and long storage; vitamin C is especially fragile. Fat-soluble vitamins (A, D, E, K) are more stable to cooking, and eating them with some fat improves absorption: carotenes in carrots and sweet potatoes, which the body turns into vitamin A, are absorbed better from cooked vegetables with a little oil. Good cooking for vitamins means quick methods with little water (steaming, stir-frying, microwaving), cutting vegetables close to cooking time, and eating a variety of colorful fruits and vegetables. Most people can meet their vitamin needs from a varied diet; questions about vitamin pills or medical needs belong to a family and its doctor.

Let's cook. You will stir-fry a colorful mix of vegetables quickly over high heat, a method that keeps color, crunch and vitamins. The skill is **quick cooking**: everything cut before the pan is hot, and the vegetables cooked just until crisp-tender.

PICTURE STUDY



Casimir Funk in His Laboratory, Unknown photographer, c. 1930s · Photograph · Reproduced on Wikimedia Commons

Image: Wikimedia Commons, public domain

Casimir Funk (1884–1967) coined the word “vitamine” in 1912 and spent his career studying vitamins and hormones. He later ran his own research laboratory in New York.

Look closely

- Find the glassware. What processes might he be carrying out?
- Look at how he works. What details show care and precision?
- Compare this laboratory with Emil Fischer’s in Lesson 4.1. What has changed?

Talk about it

1. Funk named a whole class of nutrients before most of them had been isolated. Why was that a bold idea?
2. Why do you think deficiency diseases were so hard to understand before vitamins were known?
3. How does knowing about vitamins change the way you choose and cook vegetables?

> **Safety first.** The iodine solution (povidone-iodine from a pharmacy, diluted) is for testing only: never drink it, keep it away from small children, and wash up carefully; it stains. Skip the iodine test if anyone in the family has an iodine allergy. The stir-fry uses a very hot pan; keep a lid nearby.

KITCHEN LAB

Does Cooking Destroy Vitamin C?

Vitamin C makes the blue-black color of iodine and starch disappear. The more vitamin C in a juice, the fewer drops are needed to clear a measured amount of iodine–starch solution. You will compare fresh juice with juice that was boiled or left out.

You will need

- Povidone-iodine 10% solution (first-aid antiseptic) and cornstarch
- A dropper or plastic pipette and clear small cups
- Fresh orange juice (or juice from 2 oranges), a small saucepan
- A large wok or skillet
- Your lab notebook

Rainbow Vegetable Stir-Fry

Serves 4–5 · Prep 25 min · Cook 10 min

Ingredients

- 2 tablespoons vegetable oil, divided
- 14 oz (400 g) firm tofu, pressed and cubed, or 1 lb (450 g) chicken breast, sliced
- 1 red and 1 yellow bell pepper, sliced; 2 carrots, thinly sliced; 2 cups broccoli florets; 1 cup snap peas
- 3 cloves garlic and 1 tablespoon fresh ginger, minced
- Sauce: 3 tablespoons soy sauce, 1 tablespoon honey, 1 tablespoon rice vinegar, 1 teaspoon cornstarch, ¼ cup water
- Cooked brown rice for serving

Method

1. Cut all the vegetables and mix the sauce before you turn on the heat.
2. Heat 1 tablespoon oil in the wok over high heat. Cook the tofu until golden (or the chicken until it reaches 165 °F); move to a plate.

3. Add the remaining oil, the carrots and broccoli; stir-fry 2 minutes. Add the peppers, snap peas, garlic and ginger; stir-fry 2 minutes more, until colors brighten and the vegetables are crisp-tender.
4. Return the tofu or chicken, stir the sauce, pour it in and toss until glossy, about 1 minute.
5. Serve right away over rice.
6. Wash up; refrigerate leftovers within 2 hours.

Allergy check: Contains soy (soy sauce, tofu) and wheat (soy sauce). For wheat-free, use tamari labeled gluten-free. Honey is never given to babies under one year.

Steps

1. **Make the indicator.** Stir ½ teaspoon cornstarch into ½ cup boiling water and cool. In a cup, mix 1 tablespoon of the starch solution with 10 drops of povidone-iodine and ½ cup water; it turns dark blue-black. Divide equally among test cups (same volume each).
2. **Hypothesis.** Predict which juice will need the fewest drops: fresh, boiled 10 minutes, or left uncovered at room temperature for 24 hours.
3. **Test.** Add fresh orange juice drop by drop to one cup, swirling, until the blue-black color disappears. Record the drops. Repeat three times.
4. **Treatments.** Repeat with juice boiled 10 minutes (then cooled) and juice left out 24 hours.
5. **Calculate** the average drops and the percent of vitamin C retained for each treatment.
6. **Cook** the stir-fry, noting how short the cooking time is.
7. **Conclusion.** Explain your results and give three cooking habits that protect vitamins.
8. Clean up; iodine stains: rinse cups promptly.

Tips

- Swirl after each drop and hold the cup over white paper to see the color change clearly.
- Use the same dropper and the same volume of indicator in every cup.

- Brown rice keeps more thiamin (B_1) than white rice, the lesson Eijkman's chickens taught.

Check your work

- ☐ I can tell how Eijkman, Funk and McCollum discovered vitamins.
- ☐ I can distinguish water-soluble and fat-soluble vitamins and calculate %DV.
- ☐ I measured vitamin C loss and cooked vegetables in a vitamin-friendly way.

LAB NOTEBOOK

1. Make a table of vitamins A, D, C, B_1 and K: soluble in water or fat, good food sources, deficiency disease, cooking sensitivity.
2. Record the drop data and percent retained in a bar graph.
3. Draw a rainbow plate with one vitamin-rich food for each color.

KEY FORMULAS

$$\%\,\text{DV} = \frac{\text{amount per serving}}{\text{Daily Value}} \times 100\%$$

$$\%\,\text{retained} = \frac{\text{amount after}}{\text{amount before}} \times 100\%$$

From history. Elmer McCollum also helped discover vitamin D, and his work on cod-liver oil led to the near elimination of rickets in children in countries where foods such as milk were later fortified with vitamin D. Fortifying foods with nutrients (iodized salt, enriched flour, vitamin D milk) is one of the great public-health achievements of the twentieth century.

WORKED EXAMPLES

Example 1. One cup of chopped raw red bell pepper has about 190 mg of vitamin C. Find the %DV (90 mg).

Show solution

1. $\dfrac{190}{90} \times 100\% = 211\%$.

Answer: About 211% of the Daily Value in one cup.

Example 2. In an iodine–starch test, 20 drops of orange juice decolorize the iodine solution before boiling, but 32 drops are needed after the juice is boiled for 10 minutes. What percentage of the vitamin C was retained?

Show solution

1. More drops are needed when there is less vitamin C per drop. Vitamin C per drop is proportional to $\frac{1}{\text{drops}}$.
2. $\%\,\text{retained} = \dfrac{1/32}{1/20} \times 100\% = \dfrac{20}{32} \times 100\% = 62.5\%.$

Answer: About 63% retained; boiling destroyed about 37%.

Example 3. A stir-fry serving supplies 120 mg vitamin C, 450 µg vitamin A (RAE) and 4 g fiber. The Daily Values are 90 mg, 900 µg and 28 g. Find each %DV.

Show solution

1. $\dfrac{120}{90} = 133\%$; $\dfrac{450}{900} = 50\%$; $\dfrac{4}{28} = 14\%$.

Answer: 133% vitamin C, 50% vitamin A, 14% fiber.

PRACTICE

1. Easy Who coined the word “vitamine,” and when?

   Show answer

   Casimir Funk, 1912.

2. Easy Name the four fat-soluble vitamins.

   Show answer

   A, D, E and K.

3. Easy What deficiency disease did Eijkman’s chickens show?

   Show answer

   A paralysis like beriberi (thiamin deficiency) from polished white rice.

4. Medium Why do boiled vegetables often lose more vitamin C than steamed ones?

Show answer

Vitamin C dissolves into the cooking water (which is discarded) and is damaged by long heating.

5. Medium Why are carrots' carotenes absorbed better when cooked with a little oil?

Show answer

Carotenes are fat-soluble; cooking breaks down cell walls and fat helps them be absorbed.

6. Medium A food has 27 mg of vitamin C per serving. Find %DV.

Show answer

30%.

7. Medium Fresh juice needs 15 drops and stored juice 25 drops. Find percent retained.

Show answer

60%.

8. Medium What did McCollum and Davis find in 1913?

Show answer

A growth factor in butterfat and egg yolk, "fat-soluble A" (vitamin A).

9. Hard Why was the final "e" dropped from Funk's "vitamine"?

Show answer

Many vitamins turned out not to be amines.

10. Hard Suggest three ways to keep the most vitamins when preparing broccoli.

Show answer

Cut close to cooking time, cook quickly with little water (steam, stir-fry, microwave), avoid overcooking and keeping it hot for long.

11. **Challenge** Explain how the stories of Lind (1747), Eijkman (1890s) and Funk (1912) fit together into the discovery of vitamins.

    Show answer

    Lind showed citrus cured scurvy by fair comparison; Eijkman showed a disease could come from what was missing in polished rice; Funk generalized that several diseases come from lacking specific food substances, naming them vitamins; later chemists isolated each one, including vitamin C.

COMMON MISTAKES

- Boiling vegetables a long time and pouring the water away.
- Cutting fruits and vegetables hours before eating them.
- Assuming vitamins come only from pills; a varied way of eating supplies them for most people.
- Drinking or tasting the iodine test solution.

> **Make it a game · Doctor's Diagnosis.** Your parent plays a sailor, a miller's family and a child with night blindness, describing symptoms. As the doctor, name the vitamin and the food fix. Explain water-soluble versus fat-soluble. Do five patients. Then tell how Eijkman, Funk and McCollum discovered that foods contain essential trace nutrients.

10.3 The Nutrition Facts Label and the Dietary Guidelines

OBJECTIVES

- Tell how the Nutrition Labeling and Education Act (1990) created the Nutrition Facts label (on packages from 1994), and how the label was updated in 2016 with added sugars.
- Read every part of a Nutrition Facts label, calculate %DV and teaspoons of added sugar, and compare servings.
- Bake homemade granola bars and write a Nutrition Facts panel for them from ingredient data.

> **Warm-up.** Find two packaged foods in your pantry and look at their serving sizes. Is a serving what you usually eat? How many servings are in the package?

WATCH

The New Nutrition Facts Label: Q&A With FDA's Susan Mayne

U.S. Food and Drug Administration · 6:30

https://www.youtube.com/watch?v=DTI3yOtctw4

> **WHEN TO WATCH**
> During session 1. List each change to the label that the FDA scientist describes and the reason for it.

BACKUP VIDEO

Added Sugar on the Nutrition Facts Label? Sweet!

U.S. Food and Drug Administration · 1:30

https://www.youtube.com/watch?v=I5a7E8HCvG4

After the main video. A short look at the Added Sugars line and how to read it.

KEY TERMS

serving size

The amount of a food on which the label's numbers are based, set from the amounts people typically eat.

%DV

Percent Daily Value: how much one serving contributes to a day's reference amount. As a rule of thumb, 5% or less is low and 20% or more is high.

added sugars

Sugars and syrups added during processing or preparation, as opposed to sugars naturally in fruit and milk; Daily Value 50 g.

Dietary Guidelines for Americans

Advice issued every five years by the USDA and HHS on eating patterns that support health; the 2020–2025 edition was the first to cover every stage of life.

MyPlate

The USDA's plate-shaped guide (2011) showing fruits, vegetables, grains, protein foods and dairy in a balanced meal.

CORE IDEAS

The story. Before 1990, nutrition labels in the United States were voluntary and varied from brand to brand. Congress passed the Nutrition Labeling and Education Act in 1990, and the FDA designed a standard Nutrition Facts panel, required on most packaged foods from 1994. The designer Burkey Belser created its clean black-and-white layout so that it would be easy to read and hard to disguise. In 2016 the FDA updated the label, with larger type for food energy, serving sizes based on what people actually eat, a new line for added sugars, and vitamin D and potassium in place of vitamins A and C.

How they figured it out. The FDA tested many designs with ordinary shoppers to see which ones people understood quickly and compared correctly. The updates in 2016 were based on newer nutrition science summarized in the Dietary Guidelines and on surveys of what Americans actually eat: added sugars were singled out because, on average, they made up a large share of Americans' food energy, mostly from sweetened drinks and snacks.

The kitchen science. A label tells you the amount of each nutrient in one serving and its %DV. Read it from the top: the serving size and servings per container; the food energy; then the nutrients. Use %DV to compare foods: 5% or less is low, 20% or more is high. Aim for more fiber, vitamin D, calcium, iron and potassium; be aware of added sugars, sodium and saturated fat. To picture added sugars, divide grams by 4 to get teaspoons. The **Dietary Guidelines** encourage a balanced eating pattern built mostly of vegetables, fruits, whole grains, protein foods and dairy, with added sugars below 10% of daily food energy for people over two. Labels help us steward our families' food, but they do not measure a person's worth or tell the whole story of a meal.

Let's cook. You will bake chewy granola bars and write a Nutrition Facts panel for them from the labels of your ingredients. The skill is **calculating a label**: totals divided into servings.

PICTURE STUDY



Canned Goods in a Company Store, Gary, West Virginia, U.S. government photographer, 1940s · Photograph · National Archives, College Park, Maryland

Image: Wikimedia Commons, public domain

In the 1940s, shoppers like these chose from shelves of canned and packaged foods like these, but their labels carried little or no nutrition information. Standard Nutrition Facts panels did not appear until 1994.

Look closely

- Look at the labels on the cans. What information do they seem to give?
- How would a shopper in 1946 compare two cans of beans?
- Look at how the goods are arranged. What do you think sold most?
- What foods can you recognize?

Talk about it

1. What would a 1946 shopper have gained from a Nutrition Facts label?
2. Why did the government decide that labels should look the same on every product?
3. Besides labels, what other knowledge helps a family shop wisely?

Safety first. Let the hot honey-butter mixture cool slightly before stirring it in; melted sugar holds heat. Use mitts for the 350 °F oven and let the pan cool before cutting. Check nut and seed allergies.

KITCHEN LAB

Write Your Own Nutrition Facts

You will compare the labels of two store-bought snack bars, then bake granola bars and calculate a complete Nutrition Facts panel for one bar from your ingredients.

You will need

- Two store-bought granola or snack bars (labels only are fine)
- Nutrition Facts labels for each ingredient you use
- A 9 × 13-inch pan lined with parchment, a saucepan and a spatula
- A digital scale and a calculator or spreadsheet
- Your lab notebook

Chewy Oat Granola Bars

Serves 12 bars · Prep 15 min · Bake 20–25 min · Cool 1 hr

Ingredients

- 270 g (3 cups) old-fashioned rolled oats
- 70 g (½ cup) sunflower seeds or chopped almonds
- 40 g (¼ cup) ground flaxseed
- 75 g (½ cup) raisins or chopped dried apricots
- 1 teaspoon cinnamon and ½ teaspoon salt
- 125 g (½ cup) peanut butter or sunflower-seed butter
- 110 g (⅓ cup) honey
- 55 g (¼ cup) brown sugar
- 55 g (¼ cup) butter or coconut oil
- 1 teaspoon vanilla extract

Method

1. Heat the oven to 350 °F (175 °C). Line the pan with parchment, leaving an overhang.

2. Toast the oats and seeds on a sheet pan for 8 minutes, stirring once. Combine with the flax, dried fruit, cinnamon and salt in a large bowl.
3. In a saucepan over low heat, stir the nut or seed butter, honey, brown sugar and butter until melted and smooth. Stir in the vanilla.
4. Pour over the oat mixture and stir until evenly coated. Press firmly into the pan with the back of a spatula.
5. Bake 18–22 minutes until golden at the edges. Cool completely in the pan, then lift out and cut into 12 bars.
6. Store airtight up to 1 week. Wash the saucepan and bowl.

Allergy check: Contains peanuts (peanut butter) or tree nuts (almonds) if used, and milk (butter). For a peanut- and tree-nut-free bar, use sunflower-seed butter and sunflower seeds; for milk-free, use coconut oil. Oats may contain wheat by cross-contact. Honey is never given to babies under one year.

Steps

1. **Compare.** Copy the key lines from two store-bought bar labels into a table: serving size, food energy, fiber, added sugars, protein, sodium, %DV.
2. **Gather data.** Record the mass of each ingredient you use and its nutrients per gram from its label.
3. **Calculate totals** for the whole recipe, then divide by 12 for per-bar values. Calculate %DV for fiber, added sugars, sodium and protein.
4. **Draw** a complete Nutrition Facts panel for your bar in the standard format.
5. **Compare** your bar with the store bars. Which has more fiber? More added sugar?
6. **Improve it.** Propose a change (less brown sugar, more seeds) and recalculate the label.
7. **Conclusion.** Explain what the label tells a family and what it cannot tell (taste, freshness, the joy of homemade food).
8. Clean up.

Tips

- Natural sugars in raisins count in total sugars but not added sugars; honey and brown sugar are added sugars.
- Press the mixture very firmly so the bars hold together.

- Round the panel values the way the FDA does (for example, food energy to the nearest 5 or 10 kcal).

Check your work

- ☐ I can tell how the Nutrition Facts label came to be and what changed in 2016.
- ☐ I can read a label and calculate %DV and teaspoons of added sugar.
- ☐ I wrote a Nutrition Facts panel for a recipe I baked.

LAB NOTEBOOK

1. Draw and label a Nutrition Facts panel, explaining each part in the margin.
2. Paste your granola-bar panel next to a store bar's label.
3. Sketch a MyPlate meal you would enjoy, with one food in each section.

KEY FORMULAS

$$\text{per serving} = \frac{\text{recipe total}}{\text{number of servings}}$$

$$\text{teaspoons of sugar} = \frac{\text{grams}}{4}$$

From history. The Nutrition Facts panel is widely considered a classic of information design, and many countries adopted similar labels. In 2023 the FDA proposed adding simple front-of-package labels as well, so shoppers can see key facts at a glance.

WORKED EXAMPLES

Example 1. A drink label: serving 1 bottle (591 mL), added sugars 62 g. Find the teaspoons and %DV (50 g).

Show solution

1. $\frac{62}{4} = 15.5$ tsp; $\frac{62}{50} \times 100\% = 124\%$.

Answer: About 15½ teaspoons, 124% of the Daily Value for added sugars in one bottle.

Example 2. A cereal's label says a serving is ¾ cup with 9 g added sugar. You actually pour 1½ cups. How much added sugar is that?

Show solution

1. $\dfrac{1.5}{0.75} = 2$ servings; $2 \times 9 = 18$ g.

Answer: 18 g (4½ teaspoons). Always compare the serving size with what you eat.

Example 3. The granola-bar recipe totals 1,650 kcal, 58 g fat, 252 g carbohydrate, 26 g fiber, 116 g total sugars (of which 82 g added) and 40 g protein, and makes 12 bars. Find the values per bar and the %DV for fiber and added sugars.

Show solution

1. Per bar: $\dfrac{1650}{12} = 138$ kcal, fat 4.8 g, carbohydrate 21 g, fiber 2.2 g, total sugars 9.7 g, added sugars 6.8 g, protein 3.3 g.
2. Fiber $\dfrac{2.2}{28} = 8\%$; added sugars $\dfrac{6.8}{50} = 14\%$.

Answer: About 140 kcal per bar; fiber 8% DV, added sugars 14% DV.

Example 4. For a teenager eating 2,400 kcal a day, what is the upper limit of added sugars at 10% of food energy, in grams and teaspoons?

Show solution

1. $0.10 \times 2400 = 240$ kcal; $\dfrac{240}{4} = 60$ g; 15 tsp.

Answer: About 60 g, or 15 teaspoons. A single large sweetened drink can supply all of it.

PRACTICE

1. Easy What law created the Nutrition Facts label, and when did it appear on packages?

   Show answer

   The Nutrition Labeling and Education Act of 1990; required on packages from 1994.

2. Easy What line was added in 2016?

Show answer

Added sugars (with a %DV).

3. Easy Convert 24 g of added sugar to teaspoons.

Show answer

6 teaspoons.

4. Medium A food has 12% DV of sodium per serving. Is that low or high?

Show answer

Moderate (between 5% and 20%).

5. Medium A bag says 2.5 servings, 160 kcal per serving. How much food energy in the whole bag?

Show answer

400 kcal.

6. Medium Why did the 2016 update change serving sizes?

Show answer

To reflect the amounts people actually eat, so the numbers are realistic.

7. Medium A yogurt has 15 g total sugars and 8 g added. Where do the other 7 g come from?

Show answer

Lactose naturally present in milk (and any fruit).

8. Medium A recipe totals 96 g fiber and makes 16 servings. Find fiber per serving and %DV.

Show answer

6 g; 21%.

9. Hard For 2,000 kcal a day, what is the 10% limit for added sugars in grams? How does that compare with the 50 g Daily Value?

Show answer

200 kcal ÷ 4 = 50 g; the Daily Value is set at exactly this amount.

10. Hard Two cereals: A has 6 g fiber and 12 g added sugars per 55-g serving; B has 3 g fiber and 4 g added sugars per 30-g serving. Compare per 100 g.

    Show answer

    A: 10.9 g fiber, 21.8 g added sugars. B: 10 g fiber, 13.3 g added sugars. Similar fiber; A has more added sugar.

11. Challenge Why might two foods with the same food energy have very different value in a balanced diet? Give an example.

    Show answer

    Their nutrients differ: a bowl of lentil soup and a sugary drink may have similar kcal, but the soup supplies fiber, protein, iron and folate and satisfies hunger, while the drink supplies mostly added sugar.

COMMON MISTAKES

- Ignoring the serving size.
- Confusing total sugars with added sugars.
- Treating %DV as a grade on the food or on the person.
- Tasting unbaked mixtures.

> **Make it a game · Label Audit.** Write a nutrition facts label for a recipe you know, with a serving size, percent Daily Value and added sugars line. Your parent audits it, looking for mistakes in math or placement. Fix three errors. Then explain what the 1990 law and the 2016 update changed. Compare your label with a real one on the pantry shelf.

10.4 Food Additives and GRAS: Harvey Wiley's Poison Squad

OBJECTIVES

- Tell how Harvey Wiley's "Poison Squad" experiments (1902–1907) led to the Pure Food and Drug Act (1906), and how the 1958 Food Additives Amendment created the GRAS category.
- Explain what common additives do (antioxidants, emulsifiers, leaveners, thickeners, preservatives) and how they are regulated, without fear-mongering.
- Test ascorbic acid and citric acid as anti-browning additives on cut apples, and make a fruit salad that stays bright.

> **Warm-up.** Read the ingredient list on a loaf of store bread, a box of baking powder and a jar of jam. Circle any ingredient you don't recognize. Guess what job each one does.

WATCH

FSA Explains: Food additives

FoodStandardsAgency · 1:21

https://www.youtube.com/watch?v=JU51f737Obg

> **WHEN TO WATCH**
> During session 1. Note the reasons additives are used and how they are approved before use.

Note: Short (about 1 minute) but clear; the lesson text supplies the American history and regulations.

KEY TERMS

food additive

A substance added to food for a technical purpose, such as preserving, thickening, emulsifying, leavening, coloring or flavoring.

GRAS

"Generally Recognized As Safe": a substance that qualified experts agree is safe under its intended use, based on scientific evidence or long history of common use in food.

antioxidant

A substance that slows oxidation, the reaction with oxygen that browns cut fruit and makes fats rancid. Ascorbic acid (vitamin C) and vitamin E are examples.

ADI (acceptable daily intake)

The amount of an additive that can be eaten every day over a lifetime without appreciable risk, set with large safety margins.

enzymatic browning

Browning of cut fruit caused by the enzyme polyphenol oxidase reacting phenols with oxygen.

CORE IDEAS

The story. At the beginning of the twentieth century American food was often adulterated: milk thinned with water and whitened with chalk, "honey" made of corn syrup, and foods preserved with chemicals such as borax and formaldehyde whose safety no one had tested. Harvey Washington Wiley, chief chemist of the U.S. Department of Agriculture, decided to find out. Starting in 1902, he recruited twelve young volunteer clerks, served them meals in a special dining room, and added measured doses of common preservatives to some of their food while carefully recording their health. Newspapers named them the "Poison Squad."

How they figured it out. Wiley's trials were crude by modern standards, but they were controlled comparisons with careful records, and they showed that some preservatives made the volunteers ill. His reports and campaigning, together with public outrage over conditions in meatpacking, led Congress to pass the Pure Food and Drug Act and the Meat Inspection Act in 1906, the beginning of the modern FDA. In 1958 Congress passed the Food Additives Amendment, which requires new additives to be shown safe before use; substances with a long history of safe use or strong expert agreement could be classified as GRAS (generally recognized as safe).

The kitchen science. Many additives are ordinary kitchen ingredients: salt, sugar, vinegar, baking soda and baking powder (leaveners), pectin and cornstarch (thickeners), lecithin (an emulsifier, Lesson 5.3), and ascorbic acid (vitamin C, an antioxidant). Each does a technical job. When an apple is cut, its cells break, and the enzyme polyphenol oxidase uses oxygen to turn phenol compounds into brown

pigments. Ascorbic acid prevents this by reducing the intermediate compounds back before they can brown, and acids such as citric acid slow the enzyme by lowering the pH. Today the FDA regulates additives by their use and amount: a safe substance at one level may not be at another, so regulators set limits far below the levels shown to cause any effect in testing. The scientific question about any food ingredient is not whether it sounds natural or chemical (everything is made of chemicals, including water), but what the evidence shows about the amount eaten.

Let's cook. You will test anti-browning treatments on cut apples, then make a fruit salad with a honey-lime dressing that keeps the fruit bright. The skill is **reading an ingredient list with understanding**, neither fearing nor ignoring it.

PICTURE STUDY



Harvey Wiley and the Poison Squad, U.S. Department of Agriculture photographer, c. 1903 · Photograph · U.S. Food and Drug Administration History Office

Image: Wikimedia Commons, public domain

The volunteers ate all their meals in a special dining room in the USDA building, and every bite was recorded. Their experience helped persuade Congress to pass America's first national food-safety law.

Look closely

- Find Dr. Wiley. How can you tell who is in charge?
- Look at the young men. What do you think made them volunteer?
- Look at the room. What would a laboratory dining room need?
- What questions would you have asked the volunteers?

Talk about it

1. Wiley tested additives on people. Would such an experiment be allowed today? What rules protect volunteers now?
2. Why were the 1906 food laws such an important change for American families?
3. How does the story of the Poison Squad show both the value and the limits of a single experiment?

> **Safety first.** Ascorbic acid and citric acid are food ingredients but should be measured, not eaten by the spoonful. Cut apples on a stable board with the claw grip. Check fruit allergies before the salad.

KITCHEN LAB

Keeping Apples Bright

Which treatment best prevents cut apples from browning? You will compare water, salt water, lemon juice, ascorbic acid solution and no treatment, and rate browning over time.

You will need

- Two apples of the same kind
- Five small bowls; ascorbic acid powder (or crushed vitamin C tablets), lemon juice, salt
- A knife, a cutting board, a timer and a camera
- A color scale you draw from white to dark brown (0–5)
- pH strips
- Your lab notebook

Bright Fruit Salad with Honey-Lime Dressing

Serves 6 · Prep 25 min

Ingredients

- 2 apples and 2 pears, cored and cut into bite-size pieces
- 2 bananas, sliced
- 2 cups grapes, halved
- 2 oranges, peeled and sectioned
- 1 cup berries
- Dressing: 2 tablespoons honey, 3 tablespoons lime juice, 1 teaspoon lime zest, ¼ teaspoon ascorbic acid powder (optional)

Method

1. Wash all fruit under running water.
2. Whisk the dressing in a large bowl.
3. Cut the apples, pears and bananas last and toss them into the dressing immediately to coat.

4. Add the remaining fruit and toss gently.
5. Serve within a few hours; refrigerate leftovers.
6. Wash the board and knife.

Allergy check: Contains none of the major allergens. Honey is never given to babies under one year; use maple syrup instead if needed.

Steps

1. **Prepare treatments** in five bowls: (A) nothing (dry), (B) water, (C) ½ teaspoon salt in 1 cup water, (D) 2 tablespoons lemon juice in 1 cup water, (E) ¼ teaspoon ascorbic acid in 1 cup water. Measure each pH.
2. **Hypothesis.** Rank the treatments from most to least effective and explain.
3. **Cut** apple slices of equal thickness. Dip four slices in each treatment for 1 minute, drain and set them on labeled plates.
4. **Rate** browning (0–5) and photograph at 0, 15, 30, 60 minutes and 3 hours.
5. **Graph** browning against time for each treatment.
6. **Make** the fruit salad.
7. **Read labels.** Find three additives on packages in your kitchen, identify the job each one does, and look up whether it is GRAS or an approved additive (FDA "Substances Added to Food" inventory).
8. **Conclusion.** Explain the results with enzymes, oxygen, pH and antioxidants.

Tips

- Use the same apple variety for all treatments; varieties brown at very different rates.
- Rate browning against your printed color scale rather than from memory.
- Pineapple juice also slows browning; it contains both acid and vitamin C.

Check your work

- ☐ I can tell the story of Wiley's Poison Squad and the 1906 and 1958 laws.
- ☐ I can explain what common additives do and how GRAS works, using evidence rather than fear.
- ☐ I tested anti-browning treatments and made a bright fruit salad.

LAB NOTEBOOK

1. Draw the browning reaction: enzyme + phenols + oxygen → brown pigments, and show where acid and ascorbic acid interfere.
2. Graph the browning data.
3. Make a table of five additives from your kitchen: name, job, natural source if any, and regulatory status.

KEY FORMULAS

$$\text{ppm} = \frac{m_{\text{additive}}}{m_{\text{food}}} \times 10^{6}$$

$$\text{concentration (\% w/v)} = \frac{m\ (\text{g})}{V\ (\text{mL})} \times 100\%$$

From history. After the 1906 law, Wiley led its enforcement until 1912 and later directed the Good Housekeeping laboratories. The law is often called the "Wiley Act." The FDA became a separate agency in 1930.

WORKED EXAMPLES

Example 1. You dissolve ½ teaspoon (about 2.5 g) of ascorbic acid powder in 500 mL of water. Find the concentration in % w/v and in mg per mL.

Show solution

1. $\dfrac{2.5\ \text{g}}{500\ \text{mL}} \times 100\% = 0.5\%$; $\dfrac{2500\ \text{mg}}{500\ \text{mL}} = 5\ \text{mg/mL}$.

Answer: 0.5% w/v, 5 mg per mL.

Example 2. If apple slices absorb about 2 mL of that solution per 100 g of fruit, how much vitamin C is added to a 150-g serving, and what %DV is that?

Show solution

1. $1.5 \times 2\ \text{mL} = 3\ \text{mL}$; $3 \times 5\ \text{mg} = 15\ \text{mg}$.
2. $\dfrac{15}{90} = 17\%$.

Answer: About 15 mg, 17% of the Daily Value: the anti-browning additive is also a vitamin.

Example 3. A preservative is allowed at 1,000 ppm in a beverage. How many milligrams is that in a 355-g can?

Show solution

1. $\dfrac{1000}{10^{6}} \times 355\ \text{g} = 0.355\ \text{g} = 355\ \text{mg}$.

Answer: 355 mg. Expressing limits in ppm lets regulators set the same concentration for any portion size.

Example 4. Lemon juice has a pH of about 2.3 and the apple's own juice about 3.5. How many times more acidic is lemon juice?

Show solution

1. $10^{3.5-2.3} = 10^{1.2} = 16$.

Answer: About 16 times. The extra acidity slows the browning enzyme.

PRACTICE

1. Easy What was the Poison Squad?

   Show answer

   Volunteers who ate meals with measured doses of preservatives in Harvey Wiley's USDA experiments (1902–1907).

2. Easy What does GRAS mean?

   Show answer

   Generally Recognized As Safe.

3. Easy Name two additives that are also ordinary kitchen ingredients.

   Show answer

   Any two: salt, sugar, vinegar, baking soda, baking powder, pectin, cornstarch, lecithin, ascorbic acid.

4. Medium How does ascorbic acid prevent cut fruit from browning?

   Show answer

   It is an antioxidant that reduces the browning intermediates back before they form brown pigments.

5. **Medium** Find the ppm of 0.20 g of an additive in 500 g of food.

Show answer

400 ppm.

6. **Medium** What did the 1958 Food Additives Amendment require?

Show answer

That new additives be shown safe before use, with GRAS substances recognized by expert consensus or long history of safe use.

7. **Medium** Why is “natural” versus “chemical” not a scientific test of safety?

Show answer

All foods are made of chemicals; safety depends on the substance’s properties and the amount eaten, shown by evidence.

8. **Medium** Name the job of each: pectin, lecithin, baking powder, citric acid.

Show answer

Thickener/gelling agent; emulsifier; leavener; acidulant/antioxidant aid.

9. **Hard** Make 250 mL of 0.4% w/v ascorbic acid solution.

Show answer

1.0 g ascorbic acid in water to 250 mL.

10. **Hard** Why did Wiley’s Poison Squad results help change the law even though the experiment was small?

Show answer

It was a controlled, carefully recorded test with real people that showed harm from some preservatives, and it drew public attention to untested additives.

11. **Challenge** A family member reads that an ingredient “contains chemicals” and wants to avoid it. Write a respectful, evidence-based response.

Show answer

Explain that everything, including water and apples, is made of chemicals; ask what the ingredient does and how much is used; check the FDA status and scientific evidence; respect the family’s choice while basing it on evidence rather than fear.

COMMON MISTAKES

- Judging an ingredient by whether its name is long or unfamiliar.
- Assuming an additive is harmful or harmless without looking at evidence and amount.
- Cutting apples long before serving without any treatment.
- Eating powdered ascorbic acid or citric acid straight.

> **Make it a game · Browning Bet.** Slice an apple into three pieces. Leave one plain, dip one in lemon juice and one in water. Both of you predict the order of browning and write it down, then check every five minutes for twenty. Explain enzymatic browning and antioxidants. Tell what Harvey Wiley's Poison Squad led to.

10.5 Food Technology and the Capstone: Freeze-Dried Space Food

OBJECTIVES

- Tell how NASA food scientists such as Rita Rapp developed freeze-dried and thermostabilized foods for the Apollo missions, and how technologies like freeze-drying and extrusion work.
- Explain sublimation in freeze-drying and how extrusion puffs cereals, and calculate rehydration ratios.
- Design, run and present an original food-science experiment, beginning with a model experiment on crispy roasted chickpeas.

> **Warm-up.** Look at a bag of puffed cereal, a box of instant oatmeal and a packet of instant soup. Each was made by a food-technology process. Guess how each one was made, and what problem each process solves.

WATCH

The History of Space Food

Smithsonian National Air and Space Museum · 2:23

https://www.youtube.com/watch?v=kivw3nnSt_8

> **WHEN TO WATCH**
> During session 1. Note how space food has changed from Mercury to the International Space Station, and why each change was made.

BACKUP VIDEO

The Process of Freeze Drying (Lyophilization)

BioNetwork · 3:21

https://www.youtube.com/watch?v=3DsaVLiwshY

Before the worked examples. An animation of the stages of freeze-drying: freezing, primary drying by sublimation, and secondary drying.

KEY TERMS

freeze-drying (lyophilization)

Freezing food, then lowering the pressure so the ice turns directly to vapor (sublimation), leaving a light, porous, dry food that rehydrates quickly.

sublimation

A solid changing directly to a gas without melting; ice sublimates at low pressure.

extrusion

Forcing a hot, moist dough through a shaped opening under pressure; as it exits, water flashes to steam and puffs the product (puffed cereals, some snacks and pasta shapes).

thermostabilization

Heat-processing food in sealed pouches or cans so it keeps without refrigeration (like canning).

rehydration ratio

The mass of a dried food after soaking divided by its dry mass.

capstone

A final project that brings together everything learned in a course.

CORE IDEAS

The story. When Americans began flying in space, food was a serious engineering problem: it had to be light, compact, safe for weeks without refrigeration, easy to eat without crumbs floating away, and, as astronauts insisted, good enough to want to eat. At NASA's Manned Spacecraft Center in Houston, Rita Rapp, a physiologist, led much of the work on Apollo food from the mid-1960s through the 1970s. Her team developed spoon-bowl pouches of freeze-dried and thermostabilized foods, bite-sized cubes coated to prevent crumbs, and menus the astronauts helped choose. She is remembered for treating astronauts' preferences seriously, including sending homemade sugar cookies with crews.

How they figured it out. Engineers and food scientists tested every food for weight, shelf life, safety (using HACCP, Lesson 7.4), and how it behaved in weightlessness, then refined it with feedback from astronauts. Freeze-drying, developed for medicines and blood plasma during World War II, became a key technology: it removes about 98% of the water while keeping a food's shape, flavor and most nutrients. On the International Space Station, astronauts now eat freeze-dried,

thermostabilized and irradiated foods, as well as fresh fruit from supply ships and vegetables grown on board.

The kitchen science. In **freeze-drying**, food is frozen solid, then placed in a vacuum chamber. At very low pressure, ice sublimates directly into vapor (water's triple point is about 0.006 atm), and gentle heat supplies the latent heat of sublimation (about 2,830 J/g). Because the ice leaves without melting, the food's structure stays porous, so it rehydrates quickly. In **extrusion**, a dough of grain flour and water is heated and pressurized inside a screw-driven barrel and pushed out through a die; the sudden drop in pressure flashes superheated water to steam, puffing the gelatinized starch into a crisp foam, like popcorn made continuously. Food technology at its best uses science to make food safer, more nourishing, more affordable and less wasted.

Let's cook. As a model capstone experiment, you will roast chickpeas into crunchy snacks and test how drying time affects crunch and moisture. Then you will design your own experiment.

PICTURE STUDY



Rita Rapp with Apollo 16 Food Containers, NASA photographer, 1972 · Photograph · NASA, Johnson Space Center, Houston

Image: Wikimedia Commons, public domain

Rita Rapp (1928–1989) led the Apollo food system team. She worked closely with astronauts to make sure their food was safe, nutritious and something they would enjoy.

Look closely

- Look at the containers. How are they designed for weightlessness?
- Look at Rita Rapp. What does her pose suggest about her work?
- Count the different packages. How many meals do you think they represent?

Talk about it

1. Why would astronauts' enjoyment of their food matter on a long mission?
2. Which food-science ideas from this course were needed to make space food (water activity, HACCP, freezing, packaging)?
3. What problem on Earth could food technology like this help solve?

> **Safety first.** The roasted-chickpea lab uses a 400 °F oven; use mitts and let the pan cool. Every capstone experiment must be approved by a parent before you begin, must follow the safety rules of this course (safe temperatures, no raw eggs or dough, no deep frying, no home canning of low-acid foods, no growing cultures in open containers), and must check every taster's allergies.

KITCHEN LAB

The Capstone Experiment

Food scientists design their own questions. You will first run a model experiment (how roasting time changes chickpea crunch and moisture) and then design, carry out and present an original food-science experiment that draws on at least two units of this course.

You will need

- Two cans of chickpeas, olive oil, salt and spices
- A sheet pan, oven mitts, a digital scale and a timer
- For your own capstone: whatever your approved design requires
- A computer or poster board for the presentation
- Your lab notebook

Crunchy Roasted Chickpeas

Serves 4 (about 2 cups) · Prep 10 min · Roast 30–45 min

Ingredients

- 2 cans (15 oz each) chickpeas, drained, rinsed and patted very dry
- 2 tablespoons olive oil
- ½ teaspoon salt
- 1 teaspoon smoked paprika and ½ teaspoon garlic powder (or 1 teaspoon cinnamon and 1 tablespoon sugar for a sweet version)

Method

1. Heat the oven to 400 °F (200 °C).
2. Pat the chickpeas as dry as possible with a towel; remove loose skins.
3. Toss with the oil and salt and spread in one layer on the sheet pan.
4. Roast 30–45 minutes, shaking the pan every 10 minutes, until deep golden and crunchy. (For the lab, remove samples at set times.)
5. Toss with the spices while hot. Cool completely; they crisp further as they cool.

6. Store loosely covered and eat within 2 days; airtight storage softens them.

Allergy check: Contains none of the major allergens. (Chickpeas are legumes; a few people with peanut allergy also react to other legumes.)

Steps

1. **Model experiment.** Question: how does roasting time affect crunch and moisture? Weigh 300 g of dried chickpeas; roast; remove 20-g samples at 20, 30, 40 and 50 minutes. Weigh them, calculate moisture loss, and have tasters rate crunch (0–5).
2. **Graph** mass loss and crunch against time and identify the best time.
3. **Choose your capstone question.** It must be testable in a home kitchen, involve at least two units of this course, and have one independent variable. Examples: Does resting time change cookie spread? How does salt concentration affect sauerkraut's pH over time? Which thickener makes the most freeze-stable sauce? How does blanching time affect frozen green beans' color?
4. **Write a proposal** (one page): question, hypothesis with reasoning, variables, procedure, safety plan, data table, and number of trials. Have a parent approve it.
5. **Run** the experiment with at least three trials per treatment, recording everything in your notebook.
6. **Analyze** with means, ranges, percent differences and a graph.
7. **Present** your findings to your family (and anyone else you invite) in a 5–8 minute talk or poster: background story, science, method, results, conclusion, errors and next steps.
8. **Serve** something from your experiment, with thanks.

Tips

- A good capstone question is narrow: "Does X change Y?" is better than "What makes the best bread?"
- Plan more time than you think you need, and do a small trial run first.
- Report surprising or "failed" results honestly; they are often the most interesting part.

Check your work

- ☐ I can explain freeze-drying, extrusion and how space food was developed.
- ☐ I can calculate rehydration ratios and moisture from mass data.
- ☐ I designed, ran and presented an original food-science experiment.

LAB NOTEBOOK

1. Draw a freeze-dryer: freezing shelf, vacuum chamber, condenser, with arrows for heat and water vapor.
2. Graph your chickpea data.
3. Keep your full capstone proposal, data, analysis and presentation notes.

KEY FORMULAS

$$\text{rehydration ratio} = \frac{m_{\text{rehydrated}}}{m_{\text{dry}}}$$

$$q = mL_s \quad (L_s \approx 2830\ \text{J/g for ice})$$

From history. Rita Rapp's team also designed the "spoon-bowl" package that let Apollo 8 astronauts eat with a spoon for the first time in space, on Christmas Eve 1968. Today's astronauts can choose from more than 200 foods and drinks, many developed at NASA's Space Food Systems Laboratory in Houston.

WORKED EXAMPLES

Example 1. 100 g of strawberries (91% water) are freeze-dried to 2% moisture. Find the dried mass and the water removed.

Show solution

1. Solids: 9 g; dried mass $\dfrac{9}{0.98} = 9.2$ g.
2. Water removed: $100 - 9.2 = 90.8$ g.

Answer: About 9 g of dried strawberries; about 91 g of water removed.

Example 2. How much energy is needed to sublimate the 90.8 g of ice?

Show solution

1. $q = (90.8)(2830) = 257{,}000$ J.

Answer: About 257 kJ, more than boiling it off would take, but done gently at low temperature to protect flavor.

Example 3. Freeze-dried peas weigh 25 g and 92 g after soaking. Find the rehydration ratio.

Show solution

1. $\dfrac{92}{25} = 3.7$.

Answer: 3.7. Fresh peas are about 79% water, so full rehydration would be about 4.8; the peas absorbed most but not all of their water.

Example 4. Roasted chickpeas lose mass as they dry: 300 g drained chickpeas become 165 g after 40 minutes. Canned chickpeas are about 70% water. Find the final moisture content.

Show solution

1. Solids: $0.30 \times 300 = 90$ g.
2. Water left: $165 - 90 = 75$ g; moisture $\dfrac{75}{165} = 45\%$.

Answer: About 45% moisture, still quite moist inside; crunchier chickpeas need more drying (about 10–20% moisture). Oil adds a little mass too, so this is an estimate.

PRACTICE

1. Easy What is sublimation?

   Show answer

   A solid turning directly into a gas without melting.

2. Easy Who led the Apollo food system team?

   Show answer

   Rita Rapp.

3. Easy Find the rehydration ratio for 30 g dry food that weighs 120 g after soaking.

Show answer

4.0.

4. Medium Why does freeze-dried food rehydrate faster than air-dried food?

Show answer

Ice sublimates without melting, leaving a porous structure with open channels where the ice was.

5. Medium Why must freeze-drying be done at low pressure?

Show answer

Ice sublimates readily only below water's triple-point pressure (about 0.006 atm); at normal pressure it would melt first.

6. Medium How does extrusion puff a cereal?

Show answer

Hot, pressurized dough leaves the die; the pressure drop flashes its water to steam, expanding the gelatinized starch into a foam that sets crisp.

7. Medium 500 g of apples (85% water) are freeze-dried to 3% moisture. Find the dried mass.

Show answer

$75/0.97 = 77$ g

8. Medium Name three requirements for space food.

Show answer

Light and compact, safe without refrigeration, no crumbs, nutritious, and appealing to eat.

9. Hard Find the energy to sublimate 400 g of ice (2,830 J/g), and compare it with the energy to boil away 400 g of water at 100 °C (2,260 J/g).

Show answer

1.13 MJ vs 0.90 MJ; sublimation needs more because it includes both melting and vaporization.

10. Hard Write a testable capstone question and its independent, dependent and controlled variables.

Show answer

Example: Does blanching time (1, 3, 5 min) change the color and drip loss of frozen green beans? Independent: blanching time. Dependent: color score and drip loss %. Controlled: bean batch, freezing method, thawing time, scale.

11. Challenge Describe how three earlier units of this course apply to making a pouch of freeze-dried beef stew for astronauts.

Show answer

Proteins and collagen (Unit 4) for tender meat; preservation and water activity (Unit 8) for keeping it safe dry; food safety and HACCP (Unit 7) for controlling hazards at each step; also water and heat (Unit 2) for sublimation energy.

COMMON MISTAKES

- Choosing a capstone question with too many variables.
- Running only one trial per treatment.
- Storing roasted chickpeas airtight while warm, which softens them.
- Leaving safety out of the capstone plan.

Make it a game · Pitch the Experiment. You have ninety seconds to pitch your capstone experiment: question, one independent variable, controlled variables, measurement and prediction. Your parent plays a skeptical reviewer and asks three hard questions about fairness, replication and safety. Answer each briefly. Then explain what Rita Rapp's team learned about freeze-drying and rehydration ratio for Apollo.

Scripture. “And let them gather all the food of those good years that come, and lay up corn under the hand of Pharaoh, and let them keep food in the cities. And that food shall be for store to the land against the seven years of famine, which shall be in the land of Egypt; that the land perish not through the famine.” (Genesis 41:35-36, KJV)

Joseph used wisdom and planning to preserve food for a whole nation. Food science at its best serves the same purpose: keeping good food safe so that people are fed.

UNIT 10

Nutrition Science and Food Technology

The final unit connects the chemistry and biology of food to the people who eat it and the technology that brings it to them. You will learn how food energy was measured, how vitamins were discovered, how to read the Nutrition Facts label and the Dietary Guidelines, how food additives are regulated, and how food technology from freeze-drying to extrusion fed astronauts on the way to the Moon. We treat food energy as a unit of measurement only, never something to restrict, and we weigh claims about food by evidence, not fear.

The stories follow Wilbur Atwater's calorimeter, Eijkman's chickens, Funk's "vitamine" and McCollum's vitamin A, the people who designed the Nutrition Facts label, Harvey Wiley's Poison Squad and Rita Rapp's Apollo food. The recipes are chicken burrito bowls, a rainbow vegetable stir-fry, chewy granola bars, a bright fruit salad and crunchy roasted chickpeas. The unit and the course end with your capstone: an original food-science experiment you design, carry out and present.

PREREQUISITES

- Units 1–9, especially experimental design (Unit 1), water and heat (Unit 2), carbohydrates and fiber (Unit 3) and preservation (Unit 8)
- Percentages, ratios, unit conversions and graphing
- A parent's approval for the capstone plan

MASTERY CHECKLIST

- ☐ I can explain how food energy is measured and calculate it with the Atwater factors, as energy only.
- ☐ I can explain the discovery of vitamins, water- and fat-soluble vitamins, and cooking that protects them.
- ☐ I can read a Nutrition Facts label, calculate %DV and teaspoons of added sugar, and write a panel for a recipe.
- ☐ I can explain what food additives do and how they are regulated (GRAS, the 1906 and 1958 laws), using evidence.
- ☐ I can explain freeze-drying and extrusion, and calculate moisture and rehydration ratios.
- ☐ I designed, ran and presented an original food-science experiment.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FDA: How to Understand and Use the Nutrition Facts Label**: Free. The FDA's own guide to every line of the label, for Lesson 10.3.
- **USDA FoodData Central**: Free online at fdc.nal.usda.gov. Nutrient data for thousands of foods, for the nutrient tables in Lessons 10.1 and 10.3.
- **Povidone-iodine and cornstarch**: For the vitamin C test in Lesson 10.2; inexpensive from a pharmacy and grocery store. The lesson can be done as a demonstration video instead.

Not required. Every recipe in this unit works in an ordinary home kitchen.
School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

10.1 Atwater's Calorimeter: Measuring Food Energy	3 sessions of 50–90 minutes
10.2 The Vitamins: Funk, McCollum and Vitamin C	3 sessions of 50–90 minutes
10.3 The Nutrition Facts Label and the Dietary Guidelines	3 sessions of 50–90 minutes
10.4 Food Additives and GRAS: Harvey Wiley's Poison Squad	3 sessions of 50–90 minutes
10.5 Food Technology and the Capstone: Freeze-Dried Space Food	3 sessions of 50–90 minutes (plus the capstone project over 2–3 weeks)

Unit 10 test

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **6 pts**
   Describe Atwater's respiration calorimeter and what it showed.

2. **7 pts**
   A meal contains 85 g carbohydrate, 40 g protein and 22 g fat. Find its food energy and the percentage from fat.

3. **5 pts**
   A bomb calorimeter's 2,500 g of water warms 1.6 °C from burning 1.0 g of a food. Find kcal/g.

4. **6 pts**
   Explain the difference between water-soluble and fat-soluble vitamins, with two examples of each and one cooking consequence.

5. **6 pts**

   Tell how Eijkman, Funk and McCollum each contributed to the discovery of vitamins.

6. **5 pts**

   Fresh juice needs 18 drops and boiled juice 30 drops to clear the iodine–starch indicator. Find the percent of vitamin C retained.

7. **7 pts**

   A snack label: serving 40 g, 180 kcal, fiber 3 g, added sugars 14 g, sodium 210 mg. Find the teaspoons of added sugar and the %DV for fiber (28 g), added sugars (50 g) and sodium (2,300 mg).

8. **5 pts**

   A package holds 3.5 servings at 140 kcal each. If you eat half the package, how much food energy is that?

9. **6 pts**

   What did the 2016 label update change, and why?

10. **6 pts**

    Describe Wiley’s Poison Squad and the two laws that followed (1906 and 1958).

11. **5 pts**

    How does ascorbic acid prevent browning, and how does lemon juice help?

12. **5 pts**

    Find the ppm of 0.15 g of an additive in 1.2 kg of food.

13. **6 pts**

    Explain freeze-drying and why the food rehydrates quickly.

14. **7 pts**

    800 g of peaches (88% water) are freeze-dried to 3% moisture. Find the dried mass and the energy to sublimate the ice (2,830 J/g).

15. **18 pts**

Short essay (7–9 sentences): Describe your capstone experiment as a scientist would in a short report: the question, hypothesis, variables, method and safety plan, results with numbers, conclusion, sources of error, and one idea for a follow-up experiment. Name at least two units of this course that your experiment drew on.

ANSWER KEY

1. A sealed, insulated chamber where a person lived for days while heat, oxygen and carbon dioxide were measured; it showed energy is conserved in the body and gave the 4-4-9 factors.
2. $340 + 160 + 198 = 698$ kcal; fat 28%.
3. 4.0 kcal/g.
4. Water-soluble (C, B vitamins) dissolve in water and are lost in cooking water and heat; fat-soluble (A, D, E, K) dissolve in fat, are more stable and are absorbed better with fat.
5. Eijkman linked polished rice to a beriberi-like disease in chickens (1890s); Funk proposed "vitamines" for deficiency diseases (1912); McCollum and Davis found fat-soluble A (1913).
6. 60%.
7. 3.5 tsp; fiber 11%, added sugars 28%, sodium 9%.
8. 245 kcal.
9. Added sugars line, realistic serving sizes, larger food-energy type, vitamin D and potassium; based on newer science and on what people actually eat.
10. Volunteers ate measured preservatives under observation (1902–07); the 1906 Pure Food and Drug Act; the 1958 Food Additives Amendment required pre-approval of new additives and created GRAS.
11. Ascorbic acid is an antioxidant that reverses browning intermediates; lemon juice's acid lowers pH and slows the enzyme (and supplies vitamin C).
12. 125 ppm.
13. Food is frozen, then ice sublimates under vacuum with gentle heat; the ice leaves without melting, leaving a porous structure that absorbs water quickly.
14. Solids 96 g; dried 99 g; ice removed 701 g; $q = 1.98 \times 10^6$ J.
15. Answers vary. Full credit for a complete, honest summary with a testable question, clear variables, replicated trials, numerical results, a conclusion supported by the data, specific errors, a sensible follow-up, a safety plan, and connections to two units.

UNIT PROJECT: THE CAPSTONE REPORT AND PRESENTATION

Complete the capstone begun in Lesson 10.5: an original food-science experiment drawing on at least two units of this course. Submit a written report in the form of a short scientific paper (title, abstract, introduction with a historical story, methods with safety plan, results with tables and graphs, discussion, conclusion and references) of 4–6 pages.

Present your work to your family or a small audience in a 5–8 minute talk or poster, and serve a dish connected to your experiment, beginning with a word of thanks. Keep the report with your lab notebook as the record of a full year of laboratory food science.

LOOK FOR	WHAT IT MEANS
Question and design	A focused, testable question; one independent variable; controls; at least three trials per treatment; parent-approved safety plan.
Data and analysis	Honest, complete data with units; correct calculations; clear graphs.
Science	Results explained correctly with concepts from at least two units.
Report	Well-organized scientific paper with a historical introduction and references.
Presentation and hospitality	Clear, confident talk or poster; a dish served with thanks.

COURSE EXAM

Midterm Exam

Covers Units 1–5. Time: 100 minutes.

You have 100 minutes. A calculator is allowed; no notes. Use $c_{water} = 4.18$ J/(g·°C), $L_f = 334$ J/g, $L_v = 2{,}260$ J/g and $C = 5/9(F - 32)$. For every calculation write the formula, substitute with units and give the answer with its unit; correct work earns partial credit. Answer concept questions in complete sentences. The exam has 28 problems worth a total of 100 points.

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1. **3 pts** **Lesson 1.1**

   Five dipped cups of flour weigh 138, 142, 140, 145 and 135 g. Find the mean and the percent error compared with 120 g.

2. **4 pts** **Lesson 1.2**

   In an experiment on whether chilling dough changes cookie spread, name the independent variable, the dependent variable and three controlled variables.

3. **3 pts** **Lesson 1.2**

   Scale a 36-cookie recipe with 270 g flour to 54 cookies.

4. **4 pts** **Lesson 1.3**

   Explain, using the fire triangle, how to put out a small grease fire and why water must not be used.

5. **3 pts** **Lesson 1.4**

   Convert 165 °F and 350 °F to Celsius.

6. **3 pts** **Lesson 1.4**

   Estimate the boiling point of water at 5,500 ft.

7. **3 pts** **Lesson 1.5**

   50.0 g of kernels leave 5.5 g unpopped. Find the percent popped.

8. **3 pts** **Lesson 2.1**

   Explain why sugar dissolves in water but oil does not, using polarity and hydrogen bonds.

9. **4 pts** **Lesson 2.2**

   Find the energy to heat 2.5 kg of water from 20 °C to 100 °C.

10. **4 pts** **Lesson 2.3**

    Find the heat released when 4.0 g of steam at 100 °C condenses and cools to 37 °C on skin.

11. **3 pts** **Lesson 2.4**

    Using the $2^{\Delta T/10}$ rule, how much faster does food cook at 120 °C than at 100 °C?

12. **3 pts** **Lesson 2.5**

    Find the wavelength of 2.45-GHz microwaves.

13. **4 pts** **Lesson 3.1**

    A sorbet base has 500 g purée at 8% sugar plus 140 g sugar and 110 g water. Find its Brix.

14. **3 pts** **Lesson 3.2**

    Distinguish caramelization from the Maillard reaction.

15. **3 pts** **Lesson 3.3**

    Explain gelatinization and why a starch sauce must be brought to a simmer.

16. **4 pts** **Lesson 3.4**

    Why does bread stale faster in the refrigerator than on the counter or in the freezer?

17. **3 pts** **Lesson 3.5**

    A recipe has 54 g fiber and serves 9. Find fiber per serving and %DV.

18. **3 pts** **Lesson 4.1**

    60 mL of egg white whips to 420 mL. Find the overrun.

19. **4 pts** **Lesson 4.2**

    Why must egg dishes reach 160 °F, and why does a custard set at a higher temperature than a plain egg?

20. **4 pts** **Lesson 4.3**

Name three conditions that speed the Maillard reaction.

21. **4 pts** **Lesson 4.4**

Write the baker's percentages for 600 g flour, 420 g water, 12 g salt and 6 g yeast.

22. **3 pts** **Lesson 4.5**

Why is chuck braised for hours, and what happens to its collagen?

23. **4 pts** **Lesson 5.1**

Find the theoretical butter from 600 g of cream at 36% fat, if butter is 81% fat.

24. **3 pts** **Lesson 5.2**

Why do refined oils have higher smoke points?

25. **4 pts** **Lesson 5.3**

Explain how an emulsifier stabilizes a vinaigrette, and name one.

26. **4 pts** **Lesson 5.4**

Explain how cold butter makes pastry flaky.

27. **4 pts** **Lesson 5.5**

A spread has 6 g of fat per 14 g serving. Find its fat percentage and explain why it behaves badly in shortbread.

28. **6 pts** **Lesson Essay**

Short essay (5–7 sentences): Choose one dish from Units 1–5 and explain the science of three different changes that happen to it during cooking, using correct vocabulary and at least one number (temperature, ratio or percentage).

ANSWER KEY

1. Mean 140 g; 16.7%.
2. Independent: chilled or not. Dependent: spread (diameter). Controlled: recipe, dough-ball mass, oven temperature, pan, baking time.
3. Factor 1.5; 405 g flour.
4. Turn off the heat (heat) and cover with a lid (oxygen); water sinks, flashes to steam and throws burning oil.
5. 74 °C and 177 °C.
6. $212 - 11 = 201\ ^\circ\text{F}$
7. 89%.
8. Water is polar; sugar's –OH groups hydrogen-bond with water; nonpolar oil cannot, so water excludes it.
9. $(2500)(4.18)(80) = 836{,}000\ \text{J}$
10. $4(2260) + 4(4.18)(63) = 9040 + 1053 = 10{,}093\ \text{J}$
11. 4 times.
12. $0.122\ \text{m}$
13. $180/750 = 24\ ^\circ\text{Bx}$
14. Caramelization: sugar alone at high heat (about 320 °F+). Maillard: sugars plus amino acids, at lower temperatures.
15. Starch granules absorb water, swell and burst, releasing chains that thicken; full thickening happens near the boil.
16. Retrogradation is fastest at refrigerator temperatures; in the freezer starch is below its glass transition and chains cannot move.
17. 6 g; 21%.
18. 600%.
19. Salmonella can be inside eggs; milk dilutes and sugar shields the proteins so more heat is needed before they bond.
20. High temperature, a dry surface, and higher (more alkaline) pH.
21. 100, 70, 2, 1.
22. Chuck is rich in collagen, which slowly unwinds into gelatin in long moist heat, making the meat tender.
23. $216/0.81 = 267\ \text{g}$

24. Refining removes free fatty acids and particles that break down and smoke at lower temperatures.
25. Its oil-loving tail sits in the oil droplet and water-loving head in the vinegar, coating droplets so they do not merge; mustard or lecithin.
26. Flat cold pieces of fat separate dough layers; in the oven their water and the dough's turn to steam and push the layers apart.
27. 43%; its large water content develops gluten and dissolves sugar, so the cookies spread and toughen.
28. Answers vary. Full credit for three correct, specific changes (for example gelatinization, Maillard browning, protein coagulation, emulsions, steam), proper vocabulary and an accurate number.

COURSE EXAM

Final Exam

Covers Units 1–10. Time: 120 minutes.

You have 120 minutes. A calculator is allowed; no notes. Use c_{water} = 4.18 J/(g·°C), L_f = 334 J/g, L_v = 2,260 J/g, 24.5 L/mol for a gas at 25 °C, the Atwater factors 4-4-9 kcal/g, 4 g of sugar per teaspoon, and C = 5/9(F − 32). Show the formula, substitution with units and the answer with its unit for every calculation. The exam has 30 problems worth a total of 100 points.

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1. **3 pts** **Lesson 1.4**

   Convert 145 °F and 40 °F to Celsius.

2. **3 pts** **Lesson 1.5**

   Why is replication necessary in an experiment?

3. **3 pts** **Lesson 2.2**

   500 g of pasta at 20 °C (c = 1.8) is added to 4,000 g of water at 100 °C. Find the mixed temperature.

4. **3 pts** **Lesson 2.3**

   Find the energy to melt 250 g of ice at 0 °C.

5. **3 pts** **Lesson 3.1**

   How much sugar must be added to 600 g of a 12 °Bx juice to reach 25 °Bx?

6. **3 pts** **Lesson 3.4**

   What is retrogradation?

7. **3 pts** **Lesson 4.3**

   How many times more acidic is pH 3 than pH 6?

8. **3 pts** **Lesson 4.4**

   Find the flour needed for 1,500 g of dough at 100% flour, 68% water, 2% salt, 1% yeast.

9. **3 pts** **Lesson 5.3**

   Make 400 mL of a 3 : 1 vinaigrette.

10. **3 pts** **Lesson 6.1**

Find the volume of CO_2 at 25 °C from 36.0 g of glucose fermented by yeast.

11. **3 pts** **Lesson 6.2**

Gas at 25 °C is heated to 100 °C. Find its expansion factor.

12. **3 pts** **Lesson 6.3**

How do the yeasts and lactic acid bacteria of sourdough contribute to bread?

13. **3 pts** **Lesson 6.4**

How much salt for 1,400 g of cabbage at 2.25%, and why must the cabbage stay under brine?

14. **4 pts** **Lesson 6.5**

100.0 g vinegar loses 3.7 g of CO_2 with excess baking soda. Find the percent acetic acid.

15. **3 pts** **Lesson 7.1**

10^6 bacteria undergo a 5-log reduction. How many remain?

16. **3 pts** **Lesson 7.2**

50 bacteria double every 20 minutes. How many after 4 hours?

17. **3 pts** **Lesson 7.3**

40 ate the ham (16 ill); 30 did not (3 ill). Find the attack rates and relative risk.

18. **3 pts** **Lesson 7.4**

Name three of the seven HACCP principles.

19. **3 pts** **Lesson 7.5**

State the two-stage cooling rule and two ways to meet it.

20. **3 pts** **Lesson 8.1**

400 g of plums (85% water) are dried to 20% moisture. Find the dried mass.

21. **3 pts** **Lesson 8.2**

How much salt makes a 5% brine with 2,000 g water?

22. **3 pts** **Lesson 8.3**

Why must green beans be pressure canned but pickles can be water-bath canned?

23. **3 pts** **Lesson 8.4**

With D = 0.21 min, how long is a 12D process?

24. **3 pts** **Lesson 8.5**

Why does fast freezing give better texture?

25. **3 pts** **Lesson 9.1**

Explain why the tongue map is a myth.

26. **3 pts** **Lesson 9.2**

What compounds produce umami synergy?

27. **3 pts** **Lesson 9.4**

Parents Tt × Tt: what fraction of children are non-tasters?

28. **3 pts** **Lesson 9.5**

Explain dopamine's role and two satiety signals, without diet language.

29. **5 pts** **Lesson 10.1–10.3**

A bowl has 60 g carbohydrate, 30 g protein and 15 g fat and 10 g added sugar. Find its food energy and the teaspoons and %DV (50 g) of added sugar.

30. **10 pts** **Lesson Essay**

Essay (8–10 sentences): Choose one food your family eats and trace it from farm to table to body, explaining the science from at least four units of this course (for example its chemistry, how it is cooked, how it is kept safe and preserved, how we taste it and what it supplies to the body), and end with what you have learned about receiving food with thanks.

ANSWER KEY

1. 63 °C and 4.4 °C.
2. Results vary by chance; repeating trials shows the scatter so real differences can be distinguished.
3. $16{,}720(100 - T) = 900(T - 20) \Rightarrow T = 95.9\ ^\circ\text{C}$
4. 83,500 J
5. $(72 + x)/(600 + x) = 0.25 \Rightarrow x = 104$ g
6. Cooked starch chains slowly re-forming ordered regions as they cool and age, firming the food.
7. 1,000 times.
8. $1500/1.71 = 877$ g
9. 300 mL oil, 100 mL vinegar.
10. $0.200 \times 2 \times 24.5 = 9.8$ L
11. $373/298 = 1.25$
12. Yeasts make CO_2 to raise the dough; bacteria make lactic and acetic acids for flavor and keeping.
13. 31.5 g; to exclude air, which molds and yeasts need, and favor lactic acid bacteria.
14. $3.7 \times 60.05/44.01 = 5.0\%$
15. 10.
16. $50 \cdot 2^{12} = 204{,}800$
17. 40% and 10%; 4.0.
18. Any three: hazard analysis; CCPs; critical limits; monitoring; corrective actions; verification; records.
19. 135 → 70 °F within 2 h, then to 41 °F within 4 more; shallow containers, ice bath, ice wands, stirring.
20. $60/0.80 = 75$ g
21. 105 g
22. Green beans are low-acid (above pH 4.6), so botulinum spores must be destroyed at about 240 °F; pickles are acidified below pH 4.6, where spores cannot grow.
23. 2.52 minutes.

24. Many small ice crystals form, damaging fewer cells than the large crystals of slow freezing.
25. All five tastes are detected by receptor cells in taste buds all over the tongue; the map came from a 1942 misreading of 1901 data.
26. Glutamate with inosinate or guanylate.
27. ¼.
28. Dopamine signals wanting and learning what is rewarding; stomach stretch and gut hormones (CCK, PYY) signal fullness over about 20 minutes.
29. 375 kcal; 2.5 tsp; 20%.
30. Answers vary. Full credit for accurate science from at least four units with correct vocabulary and at least two numbers (temperatures, percentages or ratios), a logical farm-to-body sequence, and a thoughtful conclusion.