SCHOOL LAUNCH · EARTH SCIENCE K–8

Grade 4 Earth Science: Weather and Water

A year of true stories about the sky and the sea, from Torricelli's tube of mercury and Luke Howard's names for the clouds to the Galveston hurricane, the Blizzard of 1888, the Johnstown Flood and Matthew Fontaine Maury's "paths of the seas," each one taken apart to see how the weather works and then measured, tested and recorded with jars, balloons, thermometers and a field notebook at the kitchen table and in the backyard.

First edition

> *"In the beginning God created the heaven and the earth." (Genesis 1:1, KJV)*

Course guide

This course follows water and air through one school year in eight units: the water cycle, air and pressure, clouds, storms, forecasting, rivers and floods, the oceans, and climate zones. Each unit is built around real moments from history: Evangelista Torricelli balancing the weight of the air with a column of mercury in 1643, Luke Howard giving the clouds their Latin names, the great hurricane that struck Galveston, Texas, in 1900, the Blizzard of 1888 that buried New York, the first weather maps drawn from telegraph reports, the failure of the South Fork Dam above Johnstown, Pennsylvania, in 1889, and Matthew Fontaine Maury charting the winds and currents of the oceans from old ships' logbooks.

Every lesson follows the same path. First comes **the story**. Then **how they figured it out**: what puzzled people, what they watched, what they measured and what they changed their minds about. Then **the big idea** underneath, explained for a fourth grader: evaporation and condensation, air pressure, warm air rising, fronts, watersheds, density, latitude and sun angle. Last, the student **observes and measures**: a barometer from a jar and a balloon, a rain gauge, a cloud journal, a salt-water layer test, a model levee or a three-day forecast checked against what really happened. Every experiment ends with numbers written in the field notebook.

The thread of the year is one great circle. Water rises from the sea, rides the wind as cloud, falls as rain or snow, gathers into rivers and returns to the sea, just as Solomon wrote: "All the rivers run into the sea; yet the sea is not full" (Ecclesiastes 1:7). Along the way the student learns why storms form, how forecasters read the sky, how engineers hold back floods and why one place is a desert and another a rainforest. The year ends with a unit project that reads thirty years of the student's own town's weather, and an optional bonus unit, **Field Lab**, sets up a backyard weather station, a cloud photo log, a storm safety walk and the measuring of a real creek.

The course is written from a Christian view of creation: "In the beginning God created the heaven and the earth." (Genesis 1:1). The wind and the rain are not accidents but part of an ordered world that can be studied, measured and trusted, so that Elihu could ask, "Dost thou know the balancings of the clouds?" (Job 37:16). Scientists such as Maury studied the sea because they believed its paths were set by a faithful Creator, and students are invited to wonder at that order, to measure it honestly, and to love their neighbors by preparing wisely for storms and floods.

WHO IT IS FOR

Written for students in grade 4 (about ages 9–10) who read on their own, can measure with a ruler, read a simple thermometer and add and subtract decimals to tenths. A parent or teacher reads along, helps with hot water, ice and outdoor work, and supervises every experiment. Measurements are given in metric units with U.S. customary units in parentheses. Nothing needs to be bought beyond ordinary household items: jars, zipper bags, balloons, a thermometer, a ruler, ice, salt, food coloring and a composition notebook.

HOW TO USE THIS COURSE

The weekly rhythm. The year has 32 lessons, one a week, plus the optional four-lesson Field Lab. Session 1 (about 45 minutes) is the warm-up, the story, the core ideas, the key terms and the picture study. Session 2 (about 45 minutes) is the experiment, the worked examples, the practice and the field notebook. In the last week of each unit, add a third session for the unit review and the unit project.

The ★ quarter path. Ten lessons are marked with ★, one or two from every unit: the water cycle, Torricelli's barometer, Howard's clouds, what clouds forecast, the Galveston hurricane, red skies, the telegraph and the first weather maps, the Johnstown Flood, Maury and the paths of the seas, and latitude and sun angle. A family that wants a one-quarter course can teach only these ten and still cover every big idea of the year.

The field notebook and the experiments. Use one composition notebook for the whole year. Every experiment ends with something measured and written down: a temperature, a rainfall total, a barometer reading, a cloud name, a table or a simple graph. Date every page, write your prediction before you begin, record what really happened (even when it surprises you) and write one sentence about what you would change. Each experiment names its variable (the one thing you change) and its control (the one you leave alone). *Safety:* an adult handles hot water, the stove and anything sharp; never taste an experiment; and never go outside to watch a storm. When thunder roars, go indoors, and never walk or drive into flood water.

Worked examples and practice. Each lesson has two worked examples that show every step, followed by eight practice items, including one data table or graph to read and one experiment to design. Answers are given for every item. Let the student try first, then check together, and talk through any mistake using the "common mistakes" list.

Unit reviews and unit projects. Each unit ends with a 50-point quiz of 10 items and a unit project that pulls the unit together, such as a water-cycle poster, a week of barometer readings, a cloud photo journal, a family storm safety plan, a forecast checked against the real weather, a flood-proof model house, a salt-water layer tower or a climate chart of your own town. Keep the unit projects in one folder for the year.

A word about time. The course is written from a Christian view of creation (Genesis 1:1) and the Flood (Genesis 6–9). Deep-time names such as "Jurassic" or "Ice Age" are taught as museum words so students can read any sign or textbook. Wherever they come up, a ⏳ Thinking About Time box sets out what the sign says, what we observe, and how Christians read it, so that the student learns to tell a measurement from an interpretation.

SCOPE AND SEQUENCE

Unit 1: The Water Cycle (1–4)

The great circle of water described in Ecclesiastes; evaporation and condensation tested in bags and on cold glasses; and the water hidden underground in aquifers and wells.

Unit 2: Air and Pressure (5–8)

Torricelli discovers that air has weight; the student builds a barometer from a jar and a balloon, watches warm air rise, and learns to read highs and lows on a weather map.

Unit 3: Clouds (9–12)

Luke Howard names the clouds; the ten cloud types and what each one tells about the weather to come; fog and dew; and a cloud photo journal kept for two weeks.

Unit 4: Storms (13–16)

The Galveston hurricane of 1900 and the seawall that followed; how tornadoes form; the Blizzard of 1888; and a family storm safety plan.

Unit 5: Forecasting (17–20)

Jesus on reading the red sky; how the telegraph let forecasters gather reports and draw the first weather maps; warm and cold fronts; and a three-day forecast checked against the real weather.

Unit 6: Rivers and Floods (21–24)

The Johnstown Flood of 1889 and the dam that failed; how levees and dams hold back water; watersheds and where rain goes; and a flood-proof model house.

Unit 7: Oceans (25–28)

Matthew Fontaine Maury charts the “paths of the seas” from ships’ logbooks; how currents move; why salt water is denser than fresh; and Benjamin Franklin’s chart of the Gulf Stream.

Unit 8: Climate Zones (29–32)

Why the sun’s angle makes the tropics warm and the poles cold; how mountains make rain shadows; deserts and rainforests; and a climate chart of the student’s own town from thirty years of records.

Unit 9: Field Lab (optional bonus unit) (Optional)

Four outdoor projects for the end of the year or the summer: a backyard weather station, a cloud photo log, a storm safety walk around home and town, and the measuring of a real creek’s width, depth and speed.

MATERIALS

- **Field notebook (a graph-paper composition book)**: One for the whole year: predictions, measurements, tables, graphs, cloud sketches and weather logs.
- **An outdoor thermometer and a ruler marked in centimeters and inches**: Used in nearly every unit. A thermometer that reads both °C and °F is best.

- **Clear jars and cups, including one straight-sided jar for a rain gauge**: For condensation, the barometer, the rain gauge and the salt-water layer tests.
- **Balloons, rubber bands, drinking straws, tape and index cards**: For the jar barometer, the hot-air experiments and pointer scales.
- **Zipper bags, ice, table salt, food coloring and a measuring cup**: For evaporation in a bag, condensation, density and ocean-current experiments.
- **A baking pan, sand or soil, modeling clay and small stones**: For the watershed model, the model levee and dam, and the flood-proof house.
- **A desk lamp or flashlight and a ball or orange**: For showing sun angle and latitude in Unit 8.
- **A U.S. map or atlas and access to a printed or online weather report**: For reading highs, lows and fronts and for checking forecasts. A parent finds the town's 30-year climate chart for Lesson 8.4.
- **Optional: a camera or phone for the cloud photo journal**: Drawings in the field notebook work just as well.
- **Optional: one of the books or resources listed in a unit**: Never required. See the list in each unit.

GRADING

Grades come mostly from the experiments and the field notebook, because weather and water are learned by observing and measuring. An experiment that did not turn out as predicted but is honestly recorded and explained earns full credit.

- Experiments (prediction, careful measuring, variable and control, and the improve-it step): 30%
- Field notebook (dated pages, labeled tables and graphs, honest records): 20%
- Practice and unit quizzes (50 points each): 25%
- Unit projects: 25%

A 90–100, B 80–89, C 70–79, D 60–69. Below 60: redo the experiment or quiz with help.

- Grade the process, not just the result. Did the student predict, measure carefully, name the variable and the control, record honestly and suggest an improvement?
- A notebook page earns full marks when it has a date, a title, a prediction, labeled measurements with units and one sentence about what the numbers mean.
- Unit quizzes may be done orally for a student who writes slowly; the parent writes down the answers.
- Keep each unit project in one folder. Together they make a fine record of the year.

A NOTE TO PARENTS

You do not need to be a meteorologist to teach this course. Read the story aloud together, step outside and look at the sky, and then be the student's lab partner in the experiment. Ask "What do you think will happen?", "What did you change, and what did you keep the same?"

and “How do you know? Show me the numbers.” Those three questions are most of what a good science teacher does.

The course teaches weather and climate as physical science: the sun, the air, the water and the shape of the land. Storms and floods are taught through real history, honestly told, with the lessons people learned about building, warning and preparing. Nothing in the course asks you or your child to take a side in present-day public debates, and nothing is meant to frighten. A child who understands a storm and has a plan for it is calmer, not more afraid.

Above all, the course hopes to raise a young person who looks up at the sky with wonder, measures it with care and gives thanks to the One who “maketh small the drops of water” (Job 36:27). Keep the field notebook going even after the year ends; a child who writes down the weather every day for a year has learned more than any textbook can teach.

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Unit 8: Climate Zones

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8.4 My Town’s Climate from a 30-Year Chart

Unit 9: Bonus: Field Lab (optional)

- 9.1 Backyard Weather Station
- 9.2 Cloud Photo Log
- 9.3 Storm Safety Walk
- 9.4 Measuring a Creek

★ quarter path · ⏳ Thinking About Time box

UNIT 1

The Water Cycle

Long ago, King Solomon noticed something strange: “All the rivers run into the sea; yet the sea is not full” (Ecclesiastes 1:7). In this unit you will solve his puzzle. You will follow water on its great journey from the sea into the sky, down as rain and snow, through rivers and underground, and back to the sea again. This journey is called the **water cycle**, and God set it in motion to water the whole earth.

You will meet real scientists who measured instead of guessing: Pierre Perrault, who measured rain on the hills of France and showed that rain feeds the rivers; Stephen Hales, the country minister who weighed a sunflower to catch the water it gave off; Charles Le Roy, who watched a cold glass to find the dew point; and Henry Darcy, who poured water through pipes of sand and learned how groundwater moves. Like them, you will build a salty sea in a bowl, catch a tree’s breath in a bag, find the dew point of your own kitchen and test which kinds of ground let water through.

Along the way you will practice the skills of a real scientist: asking a question, making a prediction, changing only one thing, keeping a control, measuring in milliliters and degrees, and reading your results from tables and bar graphs.

BEFORE YOU BEGIN

- Knows that water can be a solid (ice), a liquid (water) or a gas (water vapor)
- Can read a thermometer in degrees Celsius and Fahrenheit
- Can measure liquids with a measuring cup marked in milliliters
- Can add and subtract two- and three-digit numbers and read a simple bar graph

MASTERY CHECKLIST

- I can explain Ecclesiastes 1:7 and why the sea does not overflow.
- I can draw and label the water cycle: evaporation, condensation, precipitation, runoff and groundwater.
- I can name four things that make water evaporate faster and explain transpiration.
- I can explain why a cold glass sweats and tell what the dew point is.
- I can explain how rain becomes groundwater, what the water table and an aquifer are, and how a well works.
- I can plan a fair experiment: change one thing, keep the rest the same, use a control and measure the result.

OPTIONAL BOOKS AND RESOURCES

- **USGS Water Science School** (https://www.usgs.gov/special-topics/water-science-school): Free. The U.S. Geological Survey’s pages on the water cycle, groundwater,

wells and evaporation, with clear diagrams and photos. Best read together with a parent.

- **NOAA SciJinks** (https://scijinks.gov/): Free. Short, kid-friendly articles, pictures and games from NOAA and NASA about the water cycle, clouds, dew point and weather.

1.1 Ecclesiastes 1:7, "All the rivers run into the sea" ★

OBJECTIVES

- Explain what Ecclesiastes 1:7 observes about rivers and the sea, and why the sea does not overflow.
- Name and describe the main steps of the water cycle (evaporation, condensation, precipitation and runoff) and draw them in a labeled diagram.
- Tell how Pierre Perrault used measurements of rain and river water to show that rain feeds rivers, and compare amounts of water with simple numbers.

Warm-up. Fill a clear glass halfway with water, set it on a sunny windowsill, and mark the water line with a strip of tape. Now think like a scientist: where could the water go if the line drops? Draw a quick picture of where you think some of this water might be next week. Check the tape line again at the end of the second session.

Video. Coming soon. The water cycle for kids (evaporation, condensation, precipitation, runoff and why the sea does not overflow); search NOAA SciJinks, USGS Water Science School, NASA Global Precipitation Measurement, SciShow Kids, Homeschool Pop (Alternate) and Moody Science classics.

KEY TERMS

water cycle
The path water travels over and over: from the sea and land up into the air, back down as rain or snow, and downhill to the sea again.

evaporation
Liquid water changing into an invisible gas called water vapor. The sun's heat powers most evaporation on Earth.

condensation
Water vapor cooling and changing back into tiny drops of liquid water, as in clouds.

precipitation
Water falling from clouds to the ground as rain, snow, sleet or hail.

runoff
Rain or melted snow that flows over the ground into streams, rivers, lakes and the sea.

CORE IDEAS

The story. Long ago in Jerusalem, a wise king who called himself "the Preacher, the son of David" wrote about the world he saw. Christians have long believed this writer was King Solomon. He watched the sun rise and set, the wind blow around and come back again, and the rivers of his land flow downhill to the sea. Then he wrote one of the oldest observations of water in any book: "All the rivers run into the sea; yet the sea is not full; unto the place

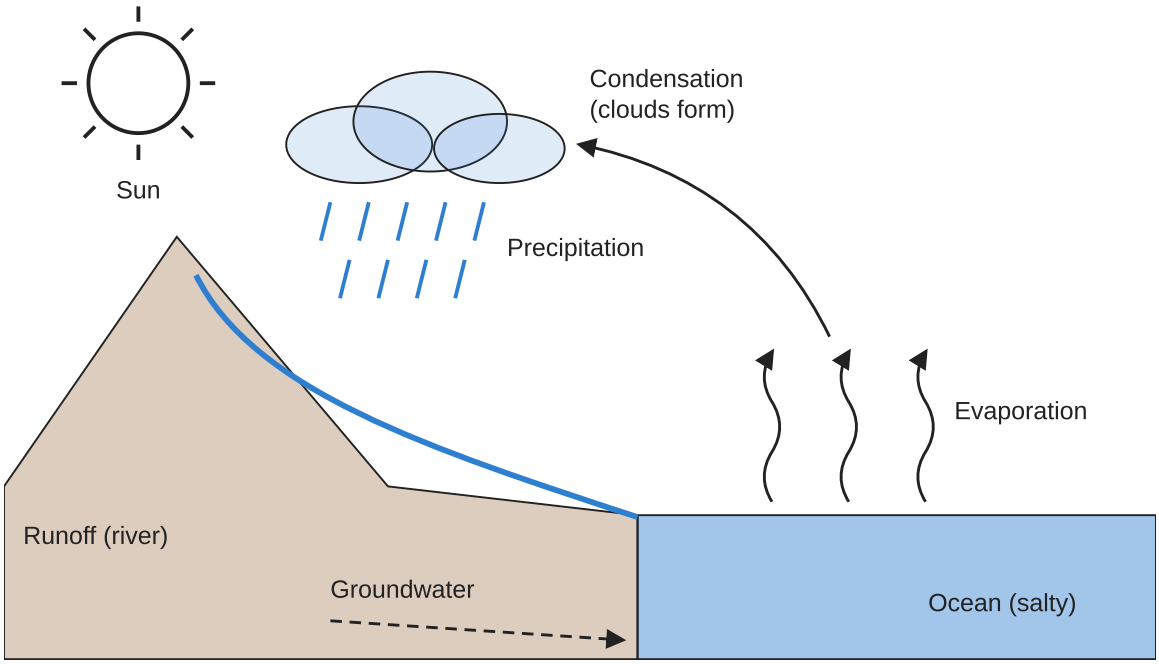
from whence the rivers come, thither they return again" (Ecclesiastes 1:7). Think about that puzzle. Rivers pour into the sea every hour of every day. Why doesn't the sea overflow? And where do the rivers keep getting their water?

How they figured it out. For many centuries, people guessed wrong about rivers. Some thought seawater crept through secret tunnels under the mountains, lost its salt along the way, and bubbled out as springs. A French official named Pierre Perrault decided to measure instead of guess. For three years, from 1668 to 1670, he kept track of the rain and snow that fell on the hills of Burgundy near the beginning of the Seine River. Then he estimated how much water the river carried away. In 1674 he published his answer in a book called *On the Origin of Springs*: the rain and snow came to about six times as much water as the river carried. Rain was more than enough to feed the river! Soon after, another French scientist, Edme Mariotte, made his own measurements and agreed.

The big idea. Water travels in a great circle called the **water cycle**. The sun warms the ocean, lakes and wet ground, and some of the water turns into an invisible gas called water vapor. This is **evaporation**. Warm, moist air rises and cools high in the sky, and the vapor turns back into tiny droplets of liquid water that we see as clouds. This is **condensation**. When the droplets join into drops too heavy to float, they fall as rain, snow, sleet or hail. This is **precipitation**. Then gravity pulls the water downhill. Some flows over the ground into streams and rivers as **runoff**, and some soaks into the ground. Sooner or later, most of it reaches the sea again, and the circle begins once more. That is why the sea is not full: the sun lifts water out of it about as fast as the rivers pour water in.

Try it and see. Here is a surprise: when seawater evaporates, the salt stays behind. Only pure water rises as vapor. That is why rain is fresh, even though nearly all of Earth's water, about 97 out of every 100 cups, is salty ocean water. In this lesson you will make a small salty "sea" in a bowl, cover it and cool the top with ice. Drops will form on the cover and rain down into a cup in the middle, and you can test whether your rain is salty. Today scientists at the U.S. Geological Survey and the National Weather Service measure rain with gauges and rivers with stream gauges, much as Perrault did, only with better tools.

God's handiwork. The same water goes around this cycle again and again, so the rain on your roof may once have been part of the sea where Jonah sailed. Nothing is wasted. The prophet Amos praised the Lord as the One "that calleth for the waters of the sea, and poureth them out upon the face of the earth" (Amos 9:6). Solomon saw the pattern long before anyone measured it, and Perrault's numbers showed how faithfully it works. When you watch a puddle dry up or a cloud drift by, you are watching one small part of a great system God set in motion to water the whole earth.



The water cycle. The sun powers evaporation; gravity brings rain, rivers and groundwater back down to the sea.

PICTURE STUDY



The Oxbow (View from Mount Holyoke, Northampton, Massachusetts, after a Thunderstorm), Thomas Cole, 1836 · Oil on canvas · The Metropolitan Museum of Art, New York

Thomas Cole was an American painter who loved the mountains, forests and rivers of New York and New England. In this painting he climbed Mount Holyoke in Massachusetts and looked down on the Connecticut River, which bends in a loop shaped like an oxbow, the U-shaped collar that holds an ox to its yoke. A thunderstorm is just passing over.

This painting is a picture of the water cycle in action. The rain falling from the storm will soak into the hills, run into streams and join the river, and the river will carry it on its way to the sea.

Look closely

- Find the storm. Can you see the gray streaks of rain falling from the clouds?
- Follow the river with your finger. Which way do you think the water is moving, and where will it end up?
- Compare the left side of the painting with the right side. What is different about the land and the light?
- Look closely near the bottom of the painting. Cole painted a tiny artist at his easel. Can you find him?

Talk about it

1. Which steps of the water cycle can you see in this painting? Which steps are happening that you cannot see?
2. Where might the rain from this storm go after it lands on the hills?
3. Why do you think Cole chose to paint the moment just after a thunderstorm?

> **Safety first.** Use warm tap water only, never boiling water, and let an adult pour it. Glass bowls can slip and break, so carry them with two hands. Taste your “rain” only with a parent’s permission, using clean bowls, cups and plastic wrap. Wipe up spills so no one slips.

EXPERIMENT: RAIN FROM A SALTY SEA

Can a salty sea make fresh rain? You will build two small “seas” in bowls and find out. You will also test a second question: does a cold lid make more rain than a lid with no ice? This is a real experiment, so you will change only one thing and keep everything else the same.

You will need

- 2 large glass or metal mixing bowls of the same size
- 2 short cups or small jars that sit well below the rims of the bowls
- 1 liter (about 1 quart) of warm tap water
- 2 teaspoons of table salt
- Blue food coloring (optional)
- Plastic wrap
- 2 coins or small smooth stones
- A zip-top bag of ice cubes
- A measuring cup marked in milliliters and a medicine syringe or measuring spoons
- Notebook and pencil, clock or timer

Steps

1. In your notebook, write the two questions: “Will rain from a salty sea be salty?” and “Will ice on top make more rain?” Write your prediction for each.
2. Pour 500 milliliters (about 2 cups) of warm tap water into each bowl. Stir 1 teaspoon of salt and one drop of blue coloring into each bowl. Each bowl must get the same amount of water, salt and coloring.
3. Set an empty cup in the middle of each bowl. Be careful not to splash any salty water into the cups.
4. Cover each bowl tightly with plastic wrap. Set a coin on the wrap right above each cup so the wrap dips down a little over the cup.
5. Label the bowls A and B. On bowl A only, set the bag of ice on the wrap, right over the coin. Bowl B gets no ice. Bowl B is your **control**: it shows what happens without the one thing you changed.
6. Put both bowls side by side in the same warm, sunny spot. Every 15 minutes for one hour, look at the underside of the wrap and write what you see.
7. After one hour, carefully lift off the wrap and lift out the cups. Measure the water in each cup with a syringe or measuring spoons and record it in milliliters.
8. Look at the water in the cups. Is it blue? With a parent’s permission, touch a clean fingertip to the cup water and taste it. Is it salty?
9. Draw your bowl in your notebook and label the four steps you saw: evaporation, condensation, precipitation and collection.

Tips

- Warmer water and colder ice both make more rain. If you see only a few drops, let the bowls sit longer.
- The salt and the coloring stay in the bowl. Only pure water evaporates, so your “rain” should be clear and fresh.
- Keep both bowls in exactly the same spot. If one sits in the sun and the other in the shade, you will not know whether the ice or the sunshine made the difference.

Check your work

- I can explain why the rain in my cup was not salty.
- I can name the one thing I changed (ice), the things I kept the same, and what I measured.
- I can label evaporation, condensation, precipitation and collection on a drawing of my bowl.

FIELD NOTEBOOK

1. Draw a full water cycle with the sun, the sea, a cloud, a mountain, rain and a river flowing back to the sea. Label each step and copy Ecclesiastes 1:7 underneath.
2. Start a rain log. Set a straight-sided jar or a rain gauge in an open place away from trees and roofs. For one week, measure the rain each morning in millimeters, empty the jar, and record each day’s amount.

3. Find the creek or river nearest your home on a map. Draw the path its water takes to the sea, and write the names of every river it joins on the way.

From history. In 1687, the English astronomer Edmond Halley, best known for the comet that bears his name, measured how fast water evaporates. He kept a pan of salty water as warm as the air on a hot summer day and weighed how much water it lost. From this he estimated how much water the sun lifts out of the Mediterranean Sea each day. Then he estimated how much water the great rivers flowing into that sea carry, including the Nile and the Danube, and found that the sun lifts out at least as much as all the rivers bring in. Together with Perrault's rain measurements, Halley's pan helped show that Solomon's words describe a real, measurable cycle.

WORKED EXAMPLES

Example 1. Like Perrault, a student studied a small valley for one year. The rain and snow that fell on the valley would fill 60 swimming pools. The stream leaving the valley carried away enough water to fill 10 swimming pools. (a) How many times more water fell than the stream carried? (b) What happened to the water that did not leave by the stream?

1. Divide the water that fell by the water the stream carried: $60 \div 10 = 6$.
2. So the rain and snow were 6 times as much as the stream carried, the same answer Perrault found for the Seine.
3. Subtract to find the water that did not leave by the stream: $60 - 10 = 50$ pools.
4. That water went back into the air by evaporation from the ground and puddles, was given off by plants through their leaves, or soaked deep into the ground.

Answer: (a) 6 times as much. (b) 50 pools of water evaporated, were given off by plants, or soaked into the ground.

Example 2. A rain gauge was read every morning for one week: Monday 5 mm, Tuesday 0 mm, Wednesday 12 mm, Thursday 3 mm, Friday 0 mm, Saturday 8 mm, Sunday 2 mm. (a) What was the total rain for the week in millimeters and in centimeters? (b) About how many inches is that? (c) Which day was wettest?

1. Add the seven days: $5 + 0 + 12 + 3 + 0 + 8 + 2 = 30$ mm.
2. There are 10 millimeters in 1 centimeter, so $30 \text{ mm} \div 10 = 3$ cm.
3. One inch is about 25 mm, so 30 mm is a little more than 1 inch: about 1.2 inches.
4. The largest number in the list is 12 mm, on Wednesday.

Answer: (a) 30 mm, which is 3 cm. (b) About 1.2 inches. (c) Wednesday, with 12 mm.

PRACTICE

1. EASY Finish the verse: “All the rivers run into the sea; yet the sea is not ____.” What puzzle about water does this verse describe?
2. EASY Name the water cycle step: (a) a puddle drying up in the sun; (b) a cloud forming high in the sky; (c) snow falling on a mountain; (d) rainwater flowing down a hill into a creek.
3. EASY What gives the water cycle the energy to lift water into the air? What pulls rain and rivers back down?
4. MEDIUM Read this rain table for one month. Week 1: 18 mm. Week 2: 25 mm. Week 3: 0 mm. Week 4: 7 mm. (a) What was the total rain for the month in millimeters and centimeters? (b) Which week was wettest? (c) Which week was a dry spell?
5. MEDIUM In one year, enough rain and snow fell on a valley to cover it 30 cm (about 12 inches) deep. The river carried away enough water to cover the valley 5 cm (about 2 inches) deep. How many times more water fell than the river carried?
6. HARD Ocean water is salty, but rain is fresh. Use what happened in your salty-bowl experiment to explain why.
7. HARD Sam wants to find out whether a dish of water loses water faster in the sun than in the shade. Plan his experiment: What should he change? What should he keep the same? What should he measure? Which dish is the control?
8. CHALLENGE Write a short story of a water drop that starts in the Gulf of Mexico, falls on a wheat farm in Kansas, and finds its way back to the Gulf. Use at least four water cycle words.

COMMON MISTAKES

- Thinking clouds are made of water vapor. Water vapor is an invisible gas; clouds are made of countless tiny droplets of liquid water or bits of ice.
- Thinking water has to boil to evaporate. Water evaporates at ordinary temperatures, which is why puddles dry up even on cool days.
- Thinking the salt rises with the water. When seawater evaporates, the salt stays behind, so rain and snow are fresh water.

Make it a game · A Drop’s Journey. Make five signs and set them around the house: Sea, Cloud, Mountain, River and Underground. Each player is a water drop and starts at the Sea. On your turn, roll a die. On 1, 2 or 3, move to the next stop in the cycle (Sea, Cloud, Mountain, River, back to Sea) and name the step that moved you there: evaporation, condensation, precipitation or runoff. On 4 or 5, stay put and tell one true fact about where you are. On 6, take a side trip: soak into the Underground and wait one turn before flowing back to the River. The first drop to make it all the way around to the Sea twice wins.

Scripture. “All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again.” (Ecclesiastes 1:7, KJV)

Solomon noticed a pattern that scientists would measure thousands of years later. Water is never used up. God sends it around and around, from the sea to the sky to the land and back to the sea, to water the whole earth.

Practice answers

1. “full.” Rivers pour water into the sea all the time, yet the sea never overflows, because water keeps evaporating from the sea and returning to the land as rain and snow.
2. (a) evaporation; (b) condensation; (c) precipitation; (d) runoff.
3. The sun’s heat powers evaporation. Gravity pulls rain down from the clouds and pulls rivers downhill to the sea.
4. (a) 18 + 25 + 0 + 7 = 50 mm, which is 5 cm (about 2 inches). (b) Week 2. (c) Week 3, with no rain.
5. 30 ÷ 5 = 6 times as much, just like Perrault’s result.
6. When salty water evaporates, only the water turns into vapor; the salt stays behind. In the bowl, the salty, colored water stayed in the bowl, and the drops that fell into the cup were clear and fresh. The sun does the same thing to the ocean, so the clouds and rain are fresh water.
7. Change: where the dish sits (sun or shade). Keep the same: the kind and size of dish, the amount of water (for example 100 mL in each), the starting time and how long they sit. Measure: how much water is left in each dish after a set time, such as 2 days, using a measuring cup. The control is the dish in the shade, which he compares with the dish in the sun.
8. Answers will vary. A good answer: The sun warms the Gulf and the drop evaporates as water vapor. Winds carry the moist air north; it rises and cools, and the vapor condenses into a cloud. The drop falls as precipitation (rain) on a wheat field in Kansas. It flows as runoff into a creek, then into the Kansas River, the Missouri River and the Mississippi River, which carries it back to the Gulf of Mexico. (It might also soak into the ground as groundwater or be taken up by a wheat plant first.)

1.2 Evaporation in a Bag

OBJECTIVES

- Explain evaporation as liquid water changing into invisible water vapor, and name four things that make it faster: heat, wind, more surface area and dry air.
- Describe transpiration and tell how Stephen Hales measured the water a sunflower gave off.
- Set up a bag experiment with a control, measure water in milliliters, and read the results from a bar graph.

Warm-up. Wet two paper towels and squeeze them out the same amount. Spread one out flat on a plate. Crumple the other into a tight ball and set it on a second plate. Predict which will dry first, and write your guess. Put both plates in the same place and check them at the end of the session. Why do you think one dried faster?

Video. Coming soon. Evaporation and transpiration for kids (water cycle in a bag, plants giving off water, why laundry dries faster in sun and wind); search USGS Water Science School, NOAA SciJinks, NASA, SciShow Kids, Science Max and Homeschool Pop (Alternate).

KEY TERMS

evaporation
The change of liquid water into water vapor, as the fastest-moving bits of water escape from the surface into the air.

water vapor
Water in the form of a gas. It is invisible and mixes into the air.

transpiration
Water leaving a plant through tiny openings in its leaves as water vapor.

surface area
How much of something is on the outside, touching the air. A flat, spread-out puddle has more surface area than the same water in a tall glass.

control
The part of an experiment that is left without the change being tested, so you can compare and see what the change really did.

CORE IDEAS

The story. In the 1720s, in the village of Teddington near London, a country minister named Stephen Hales grew a sunflower in a garden pot. Hales loved to measure the things God made, and he wanted to know how much water a plant drinks and where it goes. So he covered the soil in the pot with a thin sheet of lead, so that no water could evaporate from

the soil. The only way water could leave was through the plant itself. Then he weighed the pot and plant in the morning and again in the evening, day after day. On a warm, dry day his sunflower lost more than half a kilogram (over a pound) of water. He told about it in his book *Vegetable Staticks* in 1727.

How they figured it out. Where did the water go? Hales could not see it leave. The water had traveled up the stem, out through the leaves and into the air as an invisible gas. When water leaves a plant's leaves this way, scientists call it **transpiration**. You can catch it yourself. Tie a clear plastic bag around a leafy branch on a sunny morning, and within an hour or two the inside of the bag fogs up and drops of water collect at the bottom. A bag tied around a bare, dead stick stays dry. That second bag is a **control**: it shows that the water came from the leaves, not from the air or the bag.

The big idea. Water is made of tiny particles far too small to see, always jiggling and bumping into each other. At the surface, some of the fastest ones break free and fly off into the air as **water vapor**, an invisible gas. That is **evaporation**. Water does not have to boil to evaporate; a puddle dries even on a cool day. But four things make evaporation faster: *heat* (warm water has more fast-moving particles), *wind* (moving air carries the vapor away), more *surface area* (more water touching the air) and *dry air* (air that already holds a lot of vapor takes up more only slowly). That is why wet laundry dries fastest when it is hung out flat on a hot, breezy, dry day.

Try it and see. Pour a little water into a zip-top bag, seal it, and tape it to a sunny window. The sun warms the water and some of it evaporates. The vapor touches the cooler plastic near the top of the bag, turns back into drops, and runs down the sides like rain. Your bag holds a whole water cycle inside a few centimeters of plastic. Because the bag is sealed, the water cannot escape; it just goes around and around, the way Earth's water does.

God's handiwork. Every day the sun quietly lifts enormous amounts of water from oceans, lakes, fields and forests, and no one hears a sound. The U.S. Geological Survey reports that one large oak tree can give off about 150,000 liters (40,000 gallons) of water in a year. All that vapor rises to become clouds and rain somewhere else. The psalmist praised God for this hidden work: "He causeth the vapours to ascend from the ends of the earth" (Psalm 135:7).

PICTURE STUDY



View of Haarlem with Bleaching Fields, Jacob van Ruisdael, about 1665 · Oil on canvas · Kunsthaus Zürich, Zurich, Switzerland

Jacob van Ruisdael was a Dutch painter who lived in Haarlem, a town famous for bleaching linen. Cloth makers soaked the linen, then spread it out in long strips on the fields so the sun and air could whiten and dry it. They wet it again and again, and the sun and wind dried it again and again.

Ruisdael painted the town from a high place, so that the sky fills most of the picture. Sunlight and cloud shadows chase each other across the fields. It is a painting about weather, light and water all at once.

Look closely

- Find the long white strips on the fields. Those are pieces of linen laid out in the sun. Why would people spread them out flat instead of piling them up?
- How much of the painting is sky? Use your hand to measure it against the land.
- Find the tall church on the horizon. It is the Great Church of Saint Bavo in Haarlem.
- Look for patches of sunlight and patches of shadow on the land. What is making the shadows?

Talk about it

1. Where did the water in the wet linen go as it dried? Use the word evaporation.
2. What kind of day (hot or cold, windy or still, sunny or cloudy) would be best for bleaching and drying linen? Why?
3. Where might the water that dried from the linen be a few days later?

> **Safety first.** Plastic bags are not toys: never put one over your head or near a baby's face. Ask an adult before tying bags on any plant, and stay away from poison ivy, poison oak and thorny bushes. Stay on the ground and do not climb trees to reach a branch. Wash your hands after working outdoors.

EXPERIMENT: CATCH A TREE'S BREATH

Do leaves in the sun give off more water than leaves in the shade? Like Stephen Hales, you will catch water that you cannot see leaving a plant. You will compare a sunny branch, a shady branch and a control bag on a bare stick.

You will need

- 3 clear plastic bags of the same size (gallon zip-top bags or produce bags)
- 3 twist ties or pieces of string
- A leafy bush or tree (the same kind) with some branches in full sun and some in shade
- A bare, dead stick about as long as your arm
- A 10 mL medicine syringe or a set of measuring spoons
- Notebook, pencil and a clock or watch

Steps

1. Write your question: "Do leaves in the sun give off more water than leaves in the shade?" Write your prediction.
2. Choose two branches on the same plant: one in full sun and one in shade. Count the leaves you will put in each bag and try to make the numbers about the same, for example 20 leaves each.
3. Push the dead stick into the ground in the sun. This will be your control bag.
4. Make sure each bag is dry inside. Slip one bag over the leaves of each branch and one over the top of the dead stick. Twist the opening closed around the stem and tie it snugly, but do not crush the stem.
5. Write down the time. Check the bags every 30 minutes for 2 hours and write what you see: clear, foggy, small drops or big drops.
6. After 2 hours, gently untie each bag. Hold it so the water runs into one corner, then draw it up with the syringe (or pour it into a measuring spoon). Record how many milliliters each bag collected.
7. Make a bar graph with three bars: sunny branch, shady branch and bare stick. Write one sentence telling what you learned.

Tips

- A warm, sunny morning gives the best results. On a cool, cloudy day you may collect only a few drops.
- What you changed: sun or shade. What you kept the same: the kind of plant, the bag size, the number of leaves and the time. What you measured: milliliters of water.

- Take the bags off the same day so the branches are not harmed.
- For a bonus, seal 50 mL of water in a zip-top bag, tape it to a sunny window, and watch your own little water cycle for a few days.

Check your work

- I can explain why the bag on the bare stick is the control.
- I can measure and record water in milliliters and make a bar graph of my results.
- I can explain where the water in the bags came from, using the word transpiration.

FIELD NOTEBOOK

1. Draw your three bags after 2 hours, showing the fog and drops in each. Label the sunny bag, the shady bag and the control.
2. Draw Stephen Hales's sunflower in its pot with the lead cover over the soil, sitting on a scale. Add arrows to show where the water went.
3. Pour a cup of water on a sidewalk on a sunny day and trace the puddle's edge with chalk. Trace it again every 15 minutes. Draw the shrinking outlines in your notebook and write the times beside them.

> **From history.** Stephen Hales served as the minister of Teddington for more than fifty years, and he filled his spare hours with careful experiments. Besides weighing his sunflower, he measured how hard sap pushes up through a grapevine in spring, and he was the first person to measure blood pressure, in a horse, which he described in 1733. He also designed fans called ventilators to pump fresh air into ships and prisons, which helped keep sailors and prisoners healthier. Hales believed that studying nature carefully, with weights and measures, was a way of honoring its Maker.

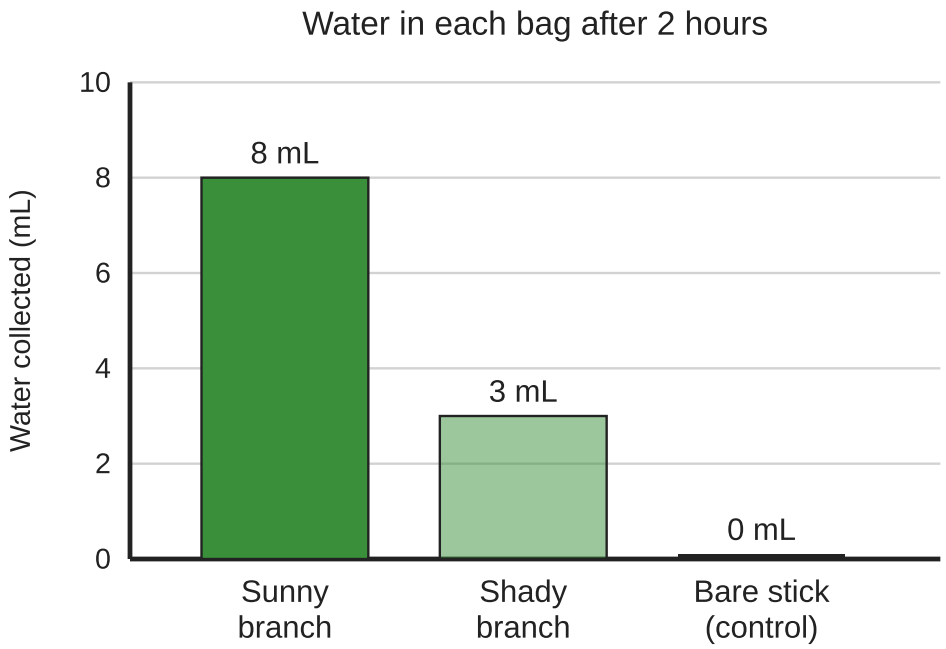
WORKED EXAMPLES

Example 1. Like Hales, a student covers the soil of a potted plant with foil so no water can evaporate from the soil. At 8 in the morning the pot weighs 2,400 grams. At 6 in the evening it weighs 2,150 grams. (a) How much water did the plant give off? (b) That was 10 hours. On average, how much water left each hour?

1. Subtract the evening weight from the morning weight: 2,400 g − 2,150 g = 250 g.
2. Because the soil was covered, the 250 g of lost weight is water that left through the leaves. 250 grams of water is 250 milliliters, about 1 cup.
3. From 8 in the morning to 6 in the evening is 10 hours.
4. Divide: 250 g ÷ 10 hours = 25 g each hour.

Answer: (a) 250 grams of water (about half a pound, or about 1 cup). (b) 25 grams each hour.

Example 2. Read the bar graph of one family's tree-bag experiment. (a) How much water did each bag collect? (b) How much more did the sunny bag collect than the shady bag? (c) What does the bare-stick bag show?



Results of a tree-bag experiment. The bare stick is the control.

1. Read the top of each bar against the scale on the left. The sunny branch bar reaches 8 mL. The shady branch bar reaches 3 mL. The bare stick has no bar: 0 mL.
2. Subtract: 8 mL − 3 mL = 5 mL more in the sunny bag.
3. The bare stick had no leaves and collected no water. This control shows that the water in the other bags came from the leaves, not from the air or the plastic.

Answer: (a) Sunny 8 mL, shady 3 mL, bare stick 0 mL. (b) 5 mL more. (c) The water came from the leaves (transpiration), and sunshine made the leaves give off more.

PRACTICE

1. EASY What is water vapor? Can you see it?
2. EASY Name four things that make water evaporate faster.
3. EASY What is transpiration?
4. MEDIUM Which will dry first: (a) a wet towel folded in a pile in a dark closet, or (b) the same towel hung flat on a clothesline on a sunny, breezy day? Explain using what you know about evaporation.
5. MEDIUM A dish of water was measured each morning. Day 1: 100 mL. Day 2: 88 mL. Day 3: 76 mL. Day 4: 64 mL. (a) How much water evaporated each day? (b) How much

evaporated in all from Day 1 to Day 4? (c) If the pattern continues, how much will be left on Day 5?

6. HARD Why did Stephen Hales cover the soil in his sunflower pot with a sheet of lead?
7. HARD Plan an experiment to find out whether wind makes water evaporate faster. You have two plates, a measuring cup, water and an electric fan. What will you change? What will you keep the same? What will you measure? Which plate is the control?
8. CHALLENGE A sealed water bag taped to a window keeps its water for weeks, but an open dish of water on the same window dries up. Explain why, and tell how the sealed bag is like the whole Earth.

COMMON MISTAKES

- Thinking the water in a drying puddle is gone forever. It has turned into water vapor and gone into the air; it will come down again as rain or snow somewhere.
- Thinking the white cloud above a hot pot or kettle is water vapor. Real water vapor is invisible; the white cloud is tiny droplets that have already cooled and condensed.
- Thinking plants only take in water and never give it off. Most of the water a plant draws up from its roots leaves through its leaves as vapor.

> **Make it a game · Fast or Slow?.** A parent describes a drying situation, such as “a wet swimsuit spread on a hot rock in the wind” or “a wet sock rolled up in a backpack.” You shout “Fast!” or “Slow!” and then name at least one reason: heat, wind, surface area or dry air. Score one point for the right answer and one more for each correct reason. Then switch: you make up a situation for your parent. Play until someone reaches ten points.

> **Scripture.** “He causeth the vapours to ascend from the ends of the earth; he maketh lightnings for the rain; he bringeth the wind out of his treasuries.” (Psalm 135:7, KJV)

Evaporation is silent and invisible, yet the psalmist knew Who lifts the vapors. Every drying puddle, every tree on a sunny day, is part of God’s work of watering the earth.

Practice answers

1. Water vapor is water in the form of a gas. It is invisible, so you cannot see it. (The white cloud above a pot of hot water is not vapor; it is tiny droplets that have already condensed.)
2. Heat (warmth), wind (moving air), more surface area (spreading the water out), and dry air.
3. Water leaving a plant through its leaves as water vapor.
4. (b). Hung flat, more of the towel touches the air (more surface area); the sun warms it (heat); and the breeze carries the water vapor away (wind). The folded towel in the closet has little surface area, no sun and still air.
5. (a) 12 mL each day (100 − 88 = 12, 88 − 76 = 12, 76 − 64 = 12). (b) 100 − 64 = 36 mL. (c) 64 − 12 = 52 mL.
6. So that no water could evaporate from the soil. Then all the weight the pot lost had to be water leaving through the sunflower’s leaves. Without the cover, he could not tell how much water came from the plant and how much came from the soil.

7. Change: one plate sits in front of the fan, the other does not. Keep the same: the kind of plate, the amount of water (for example 50 mL each), the room, the temperature and the time. Measure: how much water is left on each plate after a set time, such as 3 hours. The plate without the fan is the control.
8. In both, water evaporates. In the open dish, the vapor drifts away into the room, so the dish dries up. In the sealed bag, the vapor cannot escape; it condenses on the cooler plastic and runs back down, so the water goes around and around. Earth is like the sealed bag: water evaporates, condenses and falls again, and it stays with the earth instead of being used up.

1.3 Condensation on a Cold Glass

OBJECTIVES

- Explain condensation as water vapor cooling into liquid water, and show that the droplets on a cold glass come from the air, not through the glass.
- Define humidity and dew point, and use a thermometer and a cup of ice water to find the dew point of the air in your home.
- Connect condensation on a glass to dew, fog, clouds and a fogged-up mirror.

Warm-up. Put one metal spoon in the refrigerator or freezer for 5 minutes and leave another on the table. Breathe gently on the back of each spoon. Which one fogs up, and which fog lasts longer? Where do you think that fog came from?

Video. Coming soon. Condensation and dew point for kids (why a cold glass sweats, dew, fog and clouds forming); search NOAA SciJinks, National Weather Service education, NASA, SciShow Kids, Science Max and Homeschool Pop (Alternate).

KEY TERMS

condensation
Water vapor cooling and changing from a gas into liquid water. It is the opposite of evaporation.

humidity
How much water vapor is in the air. Humid air feels damp and muggy; dry air feels crisp.

dew point
The temperature air must cool to before its water vapor begins to condense into drops. The more water vapor in the air, the higher the dew point.

dew
Drops of water that condense on grass, leaves and other cool surfaces, usually during a clear, calm night.

fog
A cloud that forms at ground level when air near the ground cools to its dew point.

CORE IDEAS

The story. In 1751, a young doctor named Charles Le Roy lived in Montpellier, a sunny city in the south of France near the Mediterranean Sea. Everyone had seen a glass of cold water “sweat” on a summer day, but Le Roy wanted to know exactly when it happens and why. He kept a thermometer in a glass of water and made the water colder little by little. At first the outside of the glass stayed clear. Then, at a certain temperature, a thin fog of tiny droplets appeared on the outside. Le Roy noticed that this temperature changed from day to day. On

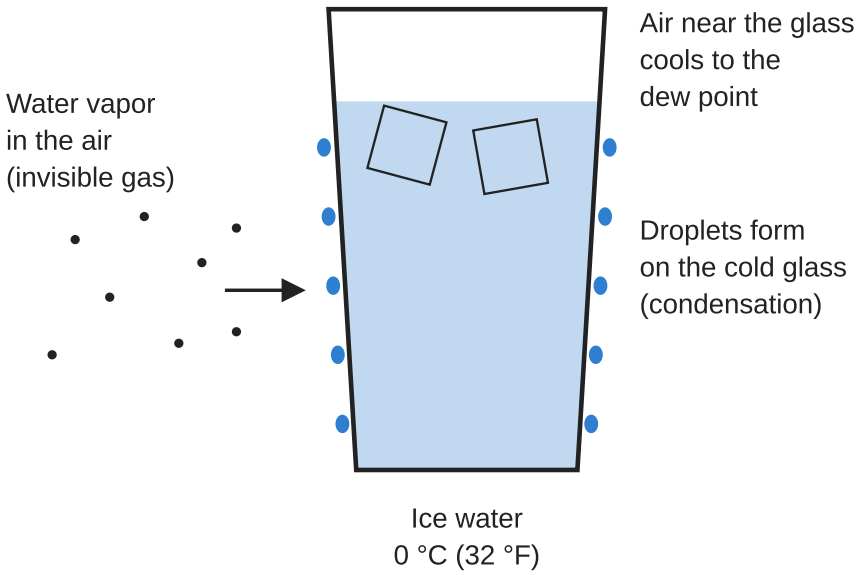
damp days, the fog appeared when the water was only a little cooler than the air. On dry days, he had to make the water much colder.

How they figured it out. Some people thought the water seeped right through the glass. But glass does not leak, and the measurements pointed another way: the water came out of the air. You can prove it yourself. Put food coloring in the ice water, and the droplets on the outside are clear, not colored. Take an empty, dry glass out of the freezer, and it fogs up too, with no water inside at all. And a glass of water at room temperature never sweats. The droplets come from invisible water vapor in the air that touches the cold glass.

The big idea. Air always holds some water vapor. The amount is called **humidity**. Warm air can hold more water vapor than cold air. When air touching a cold glass cools down, it reaches a temperature where it cannot hold all its vapor, and the extra vapor turns back into liquid drops. This change from gas to liquid is **condensation**, the opposite of evaporation. The temperature where it starts is the **dew point**. On a muggy summer day the air holds lots of vapor, so the dew point is high and even a cool glass sweats. On a dry winter day the dew point is low, and a glass must be very cold before any drops appear.

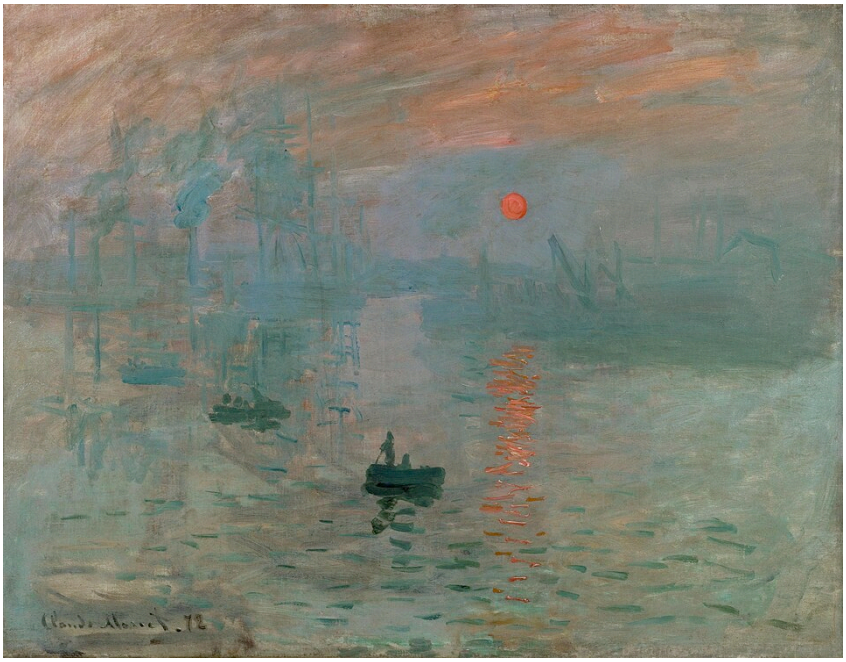
In the world today. Condensation is all around you. The bathroom mirror fogs after a hot shower. Eyeglasses fog when you walk into a warm house from the winter cold. Grass is wet with **dew** on a clear morning because the ground cooled during the night. A can of cold juice drips on a picnic table. High in the sky, rising air cools to its dew point, and the vapor condenses on tiny specks of dust or salt to make clouds; when this happens at the ground, we call it **fog**. Weather forecasters report the dew point every day, because it tells how muggy the air will feel and whether dew or fog may form overnight. You will study clouds, fog and dew more in Unit 3.

God’s handiwork. Long before anyone owned a thermometer, the book of Job described how God “maketh small the drops of water” that the clouds “do drop and distil upon man abundantly” (Job 36:27–28). The tiny drops on your glass are the same kind of drops that make every cloud in the sky. Condensation is how the vapor the sun lifted from the sea becomes visible again and comes back down to water the earth.



Why a cold glass sweats: water vapor from the air cools on the glass and condenses into drops.

PICTURE STUDY



Impression, Sunrise, Claude Monet, 1872 · Oil on canvas · Musée Marmottan Monet, Paris

Claude Monet was a French painter who wanted to catch the way light and air look at one moment. Early one morning he looked out over the harbor of Le Havre, his hometown on the coast of France, and painted it quickly before the light changed. The morning mist blurred the ships and cranes into soft shapes.

The painting's name gave a name to a whole group of painters, the Impressionists. To a scientist, the picture shows something else too: air full of tiny water droplets that have condensed over cool water in the early morning.

Look closely

- Find the sun. Look at its reflection on the water. (Remember, we look at the sun only in paintings, never in the real sky.)
- Find the small boats in front. How many people can you see in them?
- Look at the ships and cranes in the back. Why do they look so blurry and pale?
- What colors did Monet use for the mist? Are there any sharp lines in the painting?

Talk about it

1. The mist in this painting is made of tiny drops of water. Where did that water come from, and what made it condense?
2. Why might mist and fog be common over a harbor early in the morning?
3. What do you think will happen to the mist as the sun rises higher and warms the air?

> **Safety first.** Glass can break, and cut metal cans have sharp edges. Use a smooth glass or a stainless steel cup and handle it with care. Use a digital thermometer or one with red liquid, never an old silver mercury thermometer. Wipe up drips right away so no one slips.

EXPERIMENT: FIND THE DEW POINT

Like Charles Le Roy, you will cool a cup of water slowly and catch the exact temperature when droplets first appear. That temperature is the dew point of the air in your house today. You will also prove where the droplets come from.

You will need

- 2 identical cups, best if shiny metal (stainless steel) or clear glass
- Room-temperature water
- A bowl of ice cubes
- Food coloring
- A thermometer that reads °C (and °F if you have it), digital or red-liquid
- A spoon for stirring
- Paper towels, notebook, pencil and a clock

Steps

1. Write your question: "At what temperature will water vapor from the air condense on my cup?" Write your prediction.
2. Read the air temperature in the room and record it.
3. Fill both cups halfway with room-temperature water. Add 2 drops of food coloring to each. Wipe the outsides completely dry.

4. Label the cups A and B. Cup B gets no ice. It is your control.
5. Put the thermometer in cup A. Add one ice cube, stir gently, and wait one minute. Read the temperature and record it. Look closely at the outside of the cup: is it still shiny, or is it starting to look dull and foggy?
6. Keep adding one ice cube each minute, stirring and recording the temperature, until you see the first fog of tiny droplets on the outside. Record that temperature. This is your dew point.
7. Look at cup B. Did any droplets form? Touch a paper towel to the drops on cup A. Are they colored like the water inside, or clear?
8. Subtract to find how many degrees the air had to cool: air temperature minus dew point.
9. If you can, repeat the test on a rainy day, a dry day, or in the bathroom after a shower, and compare the dew points.

Tips

- What you changed: how cold the water in cup A was. What you kept the same: the kind of cup, the amount of water and the room. What you measured: the temperature when droplets first appeared.
- Do not breathe on the cup. Your breath is full of water vapor and will fog it too soon.
- A shiny metal cup shows the first fog most clearly. Look at it from the side against a light.
- On a very dry winter day, ice water may not get cold enough. Stir a spoonful of salt into the ice water to make it colder.

Check your work

- I can explain why the droplets were clear and not colored.
- I can tell what dew point is and give the dew point I measured.
- I can explain why cup B is the control.

FIELD NOTEBOOK

1. Draw cup A before and after the droplets formed. Label the thermometer reading at the moment the first fog appeared.
2. Go outside early on a clear morning and look for dew. Draw where you found it (grass, car window, spider web, leaves) and where you did not find it.
3. Keep a condensation hunt list for one week: every time you see condensation (a mirror, a window, a cold can, your breath on a cold day), write where it was and what cold surface the vapor touched.

> **From history.** In 1820, the English chemist John Frederic Daniell built an instrument called a dew-point hygrometer. It had two glass bulbs joined by a bent glass tube. Liquid evaporating inside cooled one bulb until dew formed on its outside, and a small thermometer inside showed the temperature at that moment. It worked like Le Roy’s cold

glass, only faster and more exactly. Daniell later became a professor at King's College London, and in 1836 he invented an early battery that is still called the Daniell cell.

WORKED EXAMPLES

Example 1. A student cooled a cup of water in a room where the air was 22°C (72°F). Here are the readings. 0 minutes: 22°C, no fog. 1 minute: 20°C, no fog. 2 minutes: 18°C, no fog. 3 minutes: 16°C, no fog. 4 minutes: 14°C, first fog appears. (a) What was the dew point? (b) How many degrees did the air near the cup have to cool before vapor condensed?

1. The dew point is the temperature when the first droplets appear. That happened at 4 minutes, at 14°C.
2. 14°C is about 57°F.
3. Subtract the dew point from the air temperature: 22°C − 14°C = 8°C.
4. Each degree Celsius is almost 2 degrees Fahrenheit (1.8), so a change of 8 degrees Celsius is a change of about 14 degrees Fahrenheit (8 × 1.8 = 14.4).

Answer: (a) The dew point was 14°C (about 57°F). (b) The air had to cool 8 degrees Celsius (about 14 degrees Fahrenheit).

Example 2. On Monday the dew point was 18°C (64°F). On Tuesday it was 6°C (43°F). (a) Which day had more water vapor in the air? (b) A glass of ice water is 4°C (39°F). Would it sweat on Monday? On Tuesday? (c) A glass of cool tap water is 10°C (50°F). Would it sweat on Monday? On Tuesday?

1. A higher dew point means more water vapor in the air. 18°C is higher than 6°C, so Monday was more humid.
2. A glass sweats when it is colder than the dew point. The ice water is 4°C. 4 is colder than 18, and 4 is colder than 6. So it sweats on both days.
3. The tap water is 10°C. 10 is colder than 18, so it sweats on Monday. 10 is warmer than 6, so it stays dry on Tuesday.

Answer: (a) Monday. (b) Yes on both days. (c) Yes on Monday, no on Tuesday.

PRACTICE

1. EASY What is condensation? Which water cycle step is its opposite?
2. EASY Name three places at home where you might see condensation.
3. EASY Fill in the blank: The temperature at which water vapor starts to condense is called the _____.
4. MEDIUM A glass of blue-colored ice water has clear droplets on the outside. What does this prove about where the droplets came from?

5. MEDIUM Four cups of water were set out in the same room. Read the table. Cup at 0°C (32°F): fog in 1 minute. Cup at 8°C (46°F): fog in 4 minutes. Cup at 16°C (61°F): no fog after 15 minutes. Cup at 22°C (72°F): no fog after 15 minutes. (a) Which cup fogged fastest? (b) Between which two temperatures must the dew point of the room be?
6. MEDIUM Today the dew point is 12°C. Which of these glasses will sweat: 5°C, 10°C, 15°C, 20°C?
7. HARD Plan an experiment to find out whether a metal cup or a plastic cup collects droplets faster when filled with ice water. What will you change? What will you keep the same? What will you measure?
8. CHALLENGE On Morning A the air is 22°C and the dew point is 20°C. On Morning B the air is 22°C and the dew point is 5°C. (a) Which morning is more humid? (b) If the air cools to 15°C that night, on which night is dew or fog likely? Explain.

COMMON MISTAKES

- Thinking the water on a cold glass leaks through from the inside. Glass does not leak; the water comes from vapor in the air.
- Thinking cold air "makes" water. Cooling only turns vapor that was already in the air into liquid drops. Very dry air can be cold and still form no dew.
- Thinking clouds, fog and the white puff over a kettle are water vapor. They are made of tiny liquid droplets that have already condensed; the vapor itself is invisible.

> **Make it a game · Fog or No Fog?.** A parent says a dew point and a surface temperature, such as "Dew point 15 degrees, can of juice at 5 degrees," or describes a scene, such as "warm, steamy bathroom and a cool mirror." You answer "Fog!" if the surface is colder than the dew point or "No fog!" if it is warmer, and give the reason. One point for each right answer with a reason. After five rounds, switch places: you call out the scenes and your parent answers.

> **Scripture.** "For he maketh small the drops of water: they pour down rain according to the vapour thereof: Which the clouds do drop and distil upon man abundantly." (Job 36:27–28, KJV)

Elihu tells Job that God makes the tiny drops that form clouds and fall as rain. Each droplet on your cold glass is a small picture of the way God turns invisible vapor into the rain that waters the earth.

Practice answers

1. Condensation is water vapor (a gas) cooling and changing into liquid water. Its opposite is evaporation.
2. Any three, such as: a bathroom mirror after a shower, the outside of a cold drink, a window on a cold morning, the inside of a pot lid while cooking, eyeglasses coming in from the cold, a cold spoon you breathe on.
3. Dew point.

4. The droplets did not leak through the glass, because then they would be blue. They came from clear, invisible water vapor in the air that condensed when it touched the cold glass.
5. (a) The coldest cup, at 0°C. (b) Between 8°C and 16°C, because the 8°C cup fogged but the 16°C cup did not.
6. The 5°C and 10°C glasses, because they are colder than the dew point. The 15°C and 20°C glasses stay dry.
7. Change: the cup material (metal or plastic). Keep the same: the size of the cups, the amount of water and ice in each, the starting water temperature, the room and when you start. Measure: the time (in minutes) until droplets first appear on each cup, or how wet each cup is after 10 minutes. Doing the test two or three times makes the results more trustworthy.
8. (a) Morning A, because its dew point is much higher, so the air holds more water vapor. (b) Night A. When the air cools to 15°C, it drops below its dew point of 20°C, so vapor condenses as dew or fog. On Night B, 15°C is still warmer than the dew point of 5°C, so no dew forms.

1.4 Groundwater and Wells

OBJECTIVES

- Explain how rain soaks into the ground to become groundwater, and define water table and aquifer.
- Describe how a well reaches groundwater and why the water table rises and falls with the seasons.
- Test how fast water passes through gravel, sand and clay soil, and tell how Henry Darcy measured water moving through sand.

Warm-up. Fill a clear cup to the top with dry pebbles, marbles or aquarium gravel. Do you think the cup is “full”? Slowly pour water in from a measuring cup until the water reaches the top of the pebbles. How much water fit into the spaces? Look at the cup from the side: the top of the water is like the water table underground.

Video. Coming soon. Groundwater, aquifers and wells for kids (water table, how water soaks into soil, how wells and springs work); search USGS Water Science School, the Groundwater Foundation, NOAA SciJinks, SciShow Kids, Science Max and Homeschool Pop (Alternate).

KEY TERMS

infiltration
Water soaking down into the ground from the surface.

groundwater
Water that fills the tiny spaces between grains of soil, sand and gravel and the cracks in rock below the ground.

water table
The top of the underground zone where every space is filled with water.

aquifer
A layer of sand, gravel or cracked rock that holds groundwater and lets it flow out to wells and springs.

permeable
Letting water pass through easily. Gravel and sand are permeable; clay lets water through only very slowly.

well
A hole dug or drilled down below the water table so that groundwater flows into it and can be pumped or drawn up.

CORE IDEAS

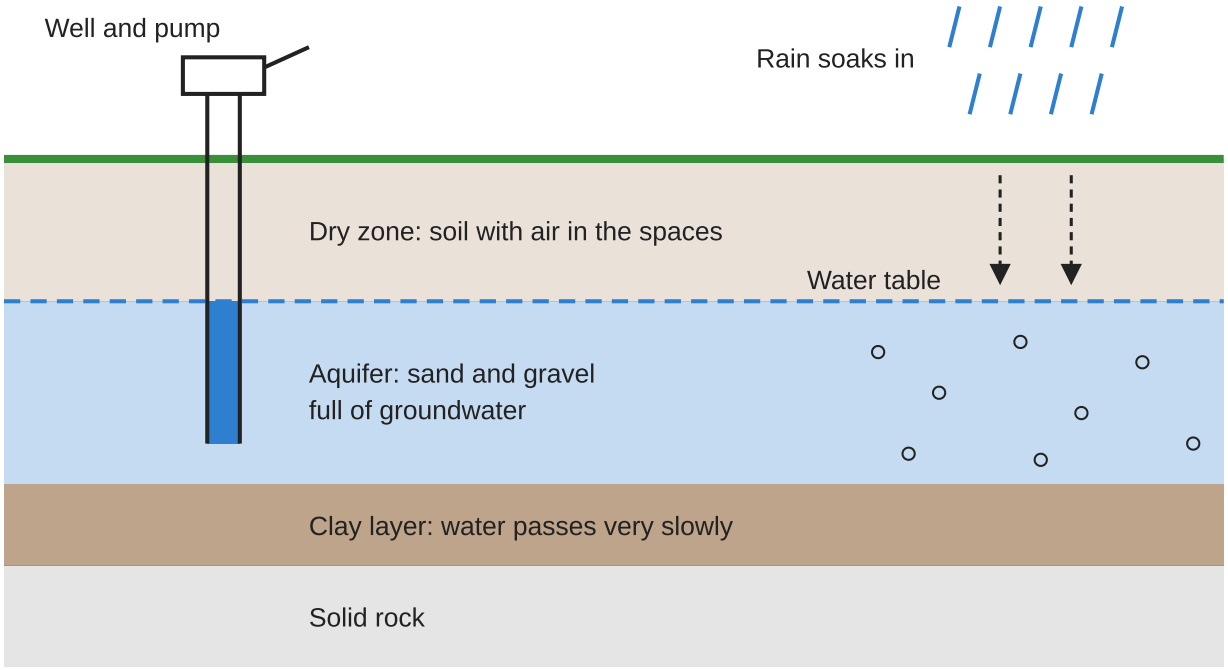
The story. In the 1830s, the city of Dijon in France had a problem: its water was poor and there was not enough of it. A young engineer named Henry Darcy, who had grown up in Dijon, found the answer underground. He brought clean water from the Rosoir spring through a covered aqueduct about 13 kilometers (8 miles) long, and by 1840 fresh water was flowing to fountains all over the city. Later, Darcy wanted to know how water moves through the sand used to filter it. So he built tall pipes filled with sand, ran water through them, and measured how fast it came out the bottom. He published his results in 1856.

How they figured it out. Darcy found two simple rules. When he put a taller column of water on top of the sand, pushing down harder, the water flowed through faster. When the water had to travel through a longer column of sand, it flowed through more slowly. Engineers still use “Darcy’s law” today to figure out how fast water moves underground and how much a well can pump. The kind of ground matters too: water races through gravel, moves steadily through sand and creeps through clay.

The big idea. When rain falls on soil, some of it soaks in. This is **infiltration**. The water trickles down through the tiny spaces between grains of soil, sand and gravel and through cracks in rock. Near the surface, the spaces hold both air and water. Deeper down, every space is full of water. This water is **groundwater**, and the top of the soaked zone is the **water table**. A layer of sand, gravel or cracked rock that holds groundwater and lets it flow is an **aquifer**. Groundwater is usually not an underground lake; it is more like water filling a sponge. Ground that lets water pass easily is **permeable**. A layer of clay below an aquifer acts like the bottom of a bathtub and holds the water up. Where the water table meets the surface on a hillside, groundwater flows out as a spring.

In the world today. A **well** is a hole that reaches below the water table, so groundwater seeps into it from the sides. Long ago, people dug wells by hand and lined them with stones. Today most wells are drilled and fitted with pipes and electric pumps, and millions of American families, especially in the country, drink water from their own wells. Most of the fresh water on Earth is frozen in ice caps and glaciers, but the U.S. Geological Survey reports that almost all the rest, about 30 out of every 100 cups of fresh water, is groundwater, far more than in all the lakes and rivers put together. The water table rises after wet seasons and falls in dry seasons, and a well that is too shallow can go dry.

God’s handiwork. Wells run all through the Bible. Abraham’s servant met Rebekah at a well (Genesis 24), Isaac dug again the wells of his father Abraham (Genesis 26:18), and Jesus rested by Jacob’s well and spoke with a woman of Samaria about “living water” (John 4:10). God stored a great treasure of clean water beneath our feet, filtered by sand and gravel as it slowly moves. Like Darcy, we can study how it works and care for it wisely, keeping wells capped and clean and not wasting what He provides.



Groundwater fills the spaces in the aquifer below the water table. A well must reach below the water table to get water.

PICTURE STUDY



Eliezer and Rebekah, Gustave Doré, 1866 · Wood engraving, from Doré's illustrated Bible · Published in Tours, France, in *La Grande Bible de Tours*; copies are in many libraries

Gustave Doré was a French artist who made hundreds of detailed engravings for books, including a famous illustrated Bible. This picture shows the story in Genesis 24, when Abraham's servant traveled far to find a wife for Isaac. He stopped at a well outside the city

of Nahor in the evening, “the time that women go out to draw water,” and Rebekah came with her pitcher on her shoulder.

In dry lands like this, a well was a gathering place and a treasure. The water came from groundwater stored in the rock and soil far below the dry surface.

Look closely

- Find the water jar. Who is holding it, and who is drinking?
- Look behind the people. The servant brought ten camels on his long journey (Genesis 24:10). What animals can you find?
- Look at the land around the well. Does it look wet or dry? Where is the water coming from?
- Notice how Doré used tiny lines to make light and shadow. Where is the light brightest?

Talk about it

1. Rebekah also drew water for all the camels (Genesis 24:19–20). Why was that a lot of hard work?
2. Why might people in a dry land dig a well instead of waiting for rain?
3. How is an ancient well like the wells families drill today? How is it different?

> **Safety first.** An adult should poke the holes in the cups with a pushpin or nail. Never drink the water from your experiment, and wash your hands after handling soil. Outdoors, never lift a well cover, lean over an old well, or play near any open hole in the ground; if you find one, stay back and tell an adult.

EXPERIMENT: WHICH GROUND LETS WATER THROUGH?

Like Henry Darcy, you will pour water through different kinds of ground and measure how much comes out. Which is most permeable: gravel, sand or clay soil? Your results will show why some ground makes a good aquifer and some does not.

You will need

- 4 clear plastic cups of the same size
- A pushpin or small nail (for an adult to poke holes)
- 4 jars or glasses that the cups can sit on top of to catch water
- Gravel (aquarium gravel or small pebbles)
- Sand (play sand)
- Clay soil (yard soil that feels sticky and smooth when wet)
- A ruler, a measuring cup marked in milliliters and a timer
- Notebook and pencil

Steps

1. Write your question: “Which lets water through fastest: gravel, sand or clay soil?” Write your prediction.
2. Have an adult poke 5 small holes in the bottom of each cup, in the same pattern for every cup.
3. Fill one cup with gravel, one with sand and one with clay soil, each 5 cm (2 inches) deep. Leave the fourth cup empty. The empty cup is your control.
4. Set each cup on top of a catching jar.
5. Pour 250 mL (about 1 cup) of water into the first cup all at once and start the timer. Watch for the first drip.
6. After 2 minutes, lift the cup off the jar. Measure the water in the jar and record it in milliliters.
7. Repeat with the other three cups, using the same amount of water and the same 2 minutes.
8. Make a table and a bar graph of your results. Rank the materials from most permeable to least permeable.
9. Subtract to find how much water each material held back: 250 mL minus the water caught.

Tips

- What you changed: the kind of material. What you kept the same: the cups, the holes, the depth of material, the amount of water and the time. What you measured: milliliters of water caught in 2 minutes.
- Clay soil may hardly drip at all in 2 minutes. That is a result too: write 0 mL if nothing comes through.
- For a bonus, build a model aquifer: in a clear jar, stand a straw against the side, then add a layer of modeling clay, a thick layer of gravel and a layer of sand. Sprinkle “rain” on top and watch the water table rise in the jar and the straw “well.” Use a turkey baster to pump water from the straw and watch the water table drop.

Check your work

- I can rank gravel, sand and clay from most to least permeable, using my measurements.
- I can explain why the empty cup is the control.
- I can explain why an aquifer is usually made of sand, gravel or cracked rock and not clay.

FIELD NOTEBOOK

1. Draw a cross-section of the ground under your house the way you imagine it: soil, the water table, an aquifer, a clay layer and rock. Add a well and label everything.
2. Visit a spring, a road cut or a creek bank with a parent. Draw the layers of soil, sand or rock you can see, and look for any place where water seeps out.

3. After a heavy rain, look at the ground in three places: a lawn, a bare dirt path and a sandy spot. Draw where puddles stayed and where water soaked in quickly.

From history. Henry Darcy died in Paris in 1858, just two years after publishing his sand experiments, but his work lives on. Scientists who study groundwater named a unit of measure after him, the darcy, which describes how easily water can flow through a kind of soil or rock. Darcy also studied water rushing through iron pipes, and engineers who design city water pipes still use a formula that carries his name, the Darcy–Weisbach equation.

WORKED EXAMPLES

Example 1. A family did the permeability test with 250 mL of water in each cup. After 2 minutes they caught: empty cup 250 mL, gravel 230 mL, sand 150 mL, clay soil 20 mL. (a) Rank the materials from most to least permeable. (b) How much water did the sand hold back? (c) Which material would make the best aquifer, and which would make a good bottom layer to hold water up?

1. The more water that came through, the more permeable the material. Order the numbers from biggest to smallest: gravel 230, sand 150, clay soil 20.
2. The empty cup let all 250 mL through. It is the control; it shows what happens with nothing in the way.
3. Subtract for the sand: 250 mL − 150 mL = 100 mL held back in the spaces between the sand grains.
4. Gravel and sand let water flow, so they make good aquifers. Clay hardly lets water through, so it makes a good bottom layer that keeps water from draining away.

Answer: (a) Gravel, then sand, then clay soil. (b) 100 mL. (c) Gravel (or sand) makes the best aquifer; clay makes a good bottom layer.

Example 2. A well is drilled 20 meters (about 66 feet) deep. The water table is 8 meters (about 26 feet) below the ground. (a) How many meters of the well are below the water table, standing in water? (b) In a dry summer, the water table drops 3 meters. How deep is the water table now, and how much of the well is still in water?

1. Subtract the depth of the water table from the depth of the well: 20 m − 8 m = 12 m. That is about 39 feet of the well below the water table.
2. In the dry summer the water table drops 3 m: 8 m + 3 m = 11 m below the ground.
3. Subtract again: 20 m − 11 m = 9 m, about 30 feet, still below the water table.

Answer: (a) 12 meters (about 39 feet). (b) The water table is 11 meters down, and 9 meters (about 30 feet) of the well is still in water, so the well still works.

PRACTICE

1. EASY What is groundwater? Is it usually a big underground lake?
2. EASY Which is more permeable, gravel or clay?
3. EASY What is the water table, and how deep must a well go to get water?
4. MEDIUM A farmer measured how far down the water table was in her well. March: 3 m. May: 4 m. July: 6 m. September: 7 m. (a) In which month was the water table closest to the surface? (b) How far did it drop from March to September, in meters and feet? (c) Give a reason it dropped.
5. MEDIUM A well is 15 m (about 49 feet) deep. The water table is 9 m below the ground. (a) How many meters of the well are in water? (b) In a long drought, the water table drops to 16 m below the ground. What happens to the well?
6. HARD A hillside has a layer of sand on top of a layer of clay. After rain, water comes trickling out of the side of the hill right where the sand meets the clay. Explain why.
7. HARD Plan an experiment to find out whether packing sand down tightly changes how fast water passes through it. What will you change? What will you keep the same? What will you measure? What would make a good comparison (control)?
8. CHALLENGE Henry Darcy found that a longer column of sand slows water down. Two pipes have the same water pushing on top. Pipe A has 1 meter of sand; Pipe B has 2 meters of the same sand. Which will let water through faster? Explain why this helps groundwater stay clean.

COMMON MISTAKES

- Thinking groundwater is mostly underground lakes and rivers. Nearly all groundwater fills the small spaces between grains and the cracks in rock, like water in a sponge.
- Thinking a well can never run dry. The water table falls in dry seasons and when too much water is pumped out, and a shallow well can go dry.
- Thinking all rain runs off into rivers. Much of it soaks into the ground, especially in sandy soil, forests and fields, and refills the groundwater.

> **Make it a game · Water Table Elevator.** You are the water table. Start by standing halfway: knees bent, hands on your knees. A parent calls out events, and you move up or down. “A week of soaking rain!” (rise up tall). “A hot, dry summer!” (sink lower). “Spring snow melts and soaks in!” (rise). “Many wells pump all day!” (sink). “A heavy rain on hard clay that all runs off!” (stay the same). If you sink all the way to a squat, the well goes dry and you must name one way to save water before standing back up. Then trade places.

> **Scripture.** “Jesus answered and said unto her, Whosoever drinketh of this water shall thirst again: But whosoever drinketh of the water that I shall give him shall never thirst; but the water that I shall give him shall be in him a well of water springing up into everlasting life.” (John 4:13–14, KJV)

Jesus sat by Jacob’s well, a well dug deep to reach groundwater, and used it to teach about Himself. Well water satisfies only for a while, but the life Jesus gives never runs dry.

Practice answers

1. Groundwater is water that fills the tiny spaces between grains of soil, sand and gravel and the cracks in rock underground. It is usually not a lake; it is more like water soaked into a sponge.
2. Gravel. Water passes through gravel easily and through clay only very slowly.
3. The water table is the top of the underground zone where every space is full of water. A well must reach below the water table.
4. (a) March (3 m down). (b) $7 - 3 = 4$ m, about 13 feet. (c) Summer usually brings less soaking rain, more evaporation in the heat, and plants and people using more water, so less water refills the ground than is taken out.
5. (a) $15 - 9 = 6$ m (about 20 feet). (b) The water table (16 m) is now deeper than the bottom of the well (15 m), so the well goes dry.
6. Rain soaks down through the permeable sand but cannot easily pass through the clay. The water collects at the bottom of the sand, on top of the clay, and flows sideways along it. Where that layer reaches the surface of the hillside, the groundwater flows out as a spring.
7. Change: how tightly the sand is packed (pressed down hard in one cup, poured loosely in the other). Keep the same: the cups and holes, the kind and amount of sand, the depth, the amount of water and the time. Measure: milliliters of water that come through in 2 minutes (or the time until the first drip). The loosely poured cup is the control to compare with the packed cup.
8. Pipe A, because the water has a shorter path through the sand. Water that travels a long way through sand and gravel moves slowly and is filtered as it goes, so dirt and many germs are trapped. That is one reason groundwater from a deep, well-built well is often clean.

Unit 1 review

Answer each question. Show your work for calculations and use complete sentences for explanations. Use the unit (mL, cm, m or °C) in every number answer. The quiz is worth 50 points.

1. (5 pts) Ecclesiastes 1:7 says, “All the rivers run into the sea; yet the sea is not full.” Explain why the sea does not overflow.
2. (5 pts) Name the water cycle step: (a) water vapor turning into cloud droplets; (b) hail falling; (c) a pond shrinking on a hot day; (d) rainwater flowing down a street into a creek.
3. (5 pts) What did Pierre Perrault measure, and what did he discover about rivers?
4. (5 pts) What is evaporation? Name three things that make it happen faster.
5. (5 pts) In the tree-bag experiment, why did we tie one bag around a bare, dead stick?
6. (5 pts) A pan of water held 200 mL on Day 1, 170 mL on Day 2 and 140 mL on Day 3. (a) How much evaporated each day? (b) If the pattern continues, how much will be left on Day 4?
7. (5 pts) A glass of red-colored ice water has clear drops on the outside. Where did the drops come from, and what is this change called?
8. (5 pts) The dew point today is 10°C (50°F). One glass of water is 4°C (39°F) and another is 15°C (59°F). Which glass will sweat? Explain.
9. (5 pts) Define water table and aquifer. Why do aquifers usually form in sand or gravel and not in clay?
10. (5 pts) A well is 18 m deep and the water table is 11 m below the ground. (a) How many meters of the well are below the water table? (b) In a drought the water table drops to 19 m below the ground. What happens to the well?

Unit project: my water cycle field book

Make a field book that tells the story of water around your home. On the first page, draw a large, colorful water cycle that includes your own house, the nearest creek or river, the clouds, the sea and the ground beneath you with its water table and a well. Label evaporation, transpiration, condensation, precipitation, runoff, infiltration and groundwater.

On the following pages, include your records from all four experiments (the salty-sea bowls, the tree bags, the dew-point cup and the permeability cups), each with its question, prediction, what you changed, what you kept the same, your measurements and a bar graph or table. Add your one-week rain log, and finish with a paragraph explaining Ecclesiastes 1:7 in your own words, using at least four things you measured or saw.

- **Science accuracy**: The water cycle drawing shows every step in the right place, with correct labels and arrows that point the right way.
- **Records**: All four experiments and the rain log are complete, dated and measured in the right units, with a control named for each experiment.

- **Explanation**: The paragraph explains why the sea is not full, using evaporation, condensation, precipitation and runoff and real evidence from the experiments.
- **Care**: The field book is neat, colorful and easy to read, with drawings made carefully from real observation.

Answer key

1. The sun’s heat keeps evaporating water from the sea into the air about as fast as rivers pour water in. The vapor forms clouds, falls as rain and snow on the land, and flows back to the sea, so the water goes around in a cycle.
2. (a) condensation; (b) precipitation; (c) evaporation; (d) runoff.
3. He measured the rain and snow falling on the hills near the beginning of the Seine River for three years and estimated how much water the river carried away. The rain and snow were about six times as much as the river carried, so rain is more than enough to feed rivers; they do not need seawater from underground tunnels.
4. Evaporation is liquid water changing into invisible water vapor. Any three of: heat, wind, more surface area, dry air.
5. It was the control. It collected no water, which showed that the water in the other bags came from the leaves (transpiration), not from the air or the plastic bag.
6. (a) 30 mL each day. (b) 140 − 30 = 110 mL.
7. They came from invisible water vapor in the air, which cooled when it touched the cold glass and turned into liquid drops. This is condensation. The drops are clear, not red, so they did not leak through the glass.
8. The 4°C glass, because it is colder than the dew point, so the air touching it cools below 10°C and its vapor condenses. The 15°C glass is warmer than the dew point, so it stays dry.
9. The water table is the top of the underground zone where every space is full of water. An aquifer is a layer of sand, gravel or cracked rock that holds groundwater and lets it flow to wells and springs. Sand and gravel are permeable, with connected spaces that let water flow; clay lets water through only very slowly.
10. (a) 18 − 11 = 7 m. (b) The water table (19 m) is now below the bottom of the well (18 m), so the well goes dry.

UNIT 2

Air and Pressure

We cannot see the air, but it is always pressing on us. In 1643 a young Italian mathematician named Evangelista Torricelli turned a tube of mercury upside down in a dish and proved that air has weight. We live, he said, at the bottom of an ocean of air. In this unit you will repeat his experiment with water, build your own barometer from a jar and a balloon, and keep a week-long log of the rising and falling air pressure over your house.

Then you will find out why the air moves. You will follow the Montgolfier brothers as their hot-air balloons rise over France and watch warm and cold water race in a glass dish to see **convection** at work. Finally you will learn to read the big **H** and **L** on a weather map, trace isobars, and use Buys Ballot's law to point toward a storm. In every lesson you will ask the same question: **what is the air pushing on, and which way will it go?**

BEFORE YOU BEGIN

- Can read a centimeter ruler and a thermometer in °C and °F
- Can add, subtract and multiply whole numbers, and subtract simple decimals
- Knows from Unit 1 that water evaporates into water vapor and condenses into droplets
- Can make a simple table and bar graph

MASTERY CHECKLIST

- I can tell how Torricelli's mercury tube showed that air has weight, and explain what air pressure is.
- I can build a jar barometer, read it, and explain why rising pressure often means fair weather and falling pressure often means storms.
- I can name temperature as a variable that must be controlled when using a homemade barometer.
- I can explain why warm air rises and how convection makes a sea breeze.
- I can read H, L and isobars on a weather map, tell what weather each brings, and tell where the wind is strongest.

OPTIONAL BOOKS AND RESOURCES

- **NOAA SciJinks** (https://scijinks.gov/): Free. NOAA's weather site for students, with short articles, pictures and games about air pressure, wind, highs and lows and weather maps.
- **National Weather Service** (https://www.weather.gov/): Free. Type in your town to find today's air pressure for your barometer log (Lessons 2.2 and 2.4). A parent can help find the national surface map that shows real highs, lows and isobars.
- **NOAA Weather Prediction Center** (https://www.wpc.ncep.noaa.gov/): Free. Forecasters post surface analysis maps of North America with H, L and isobars several

times a day. Best viewed with a parent; compare one with the map you draw in Lesson 2.4.

2.1 Torricelli's Barometer (1643) ★

OBJECTIVES

- Tell how Evangelista Torricelli used a tube of mercury in 1643 to show that air has weight.
- Explain air pressure as the push of the air above us and describe how a mercury barometer measures it.
- Test with water and a bottle that air pressure can hold up a column of liquid, and record the results.

Warm-up. Fill a drinking glass with water. Dip a straw in, put your finger tightly over the top of the straw, and lift it out. The water stays in the straw! Now lift your finger. What happened? Talk about it: what was holding the water up while your finger was on top?

Video. Coming soon. Torricelli mercury barometer and air pressure for kids: search NOAA SciJinks, NASA, SciShow Kids, Science Max, Homeschool Pop (Alternate) and Moody Science classics for air-pressure demonstrations (upside-down glass, crushed can, water in a straw).

KEY TERMS

air pressure
The push of the air on everything it touches, caused by the weight of all the air above.

atmosphere
The deep blanket of air that surrounds the whole earth.

barometer
An instrument that measures air pressure. The name comes from Greek words meaning "weight measure."

mercury
A heavy, silvery metal that is liquid at room temperature. It is poisonous, so it must never be touched.

vacuum
A space with almost nothing in it, not even air.

CORE IDEAS

The story. In the city of Florence, Italy, the well-diggers had a puzzle. Their suction pumps could lift water up out of a deep well, but never higher than about 10 meters (about 34 feet). No matter how hard they pumped, the water would not rise any farther. The great scientist Galileo wrote about this puzzle, but he died in 1642 without solving it. His young helper, a mathematician named **Evangelista Torricelli**, kept thinking about it. In 1643, working with

his friend Vincenzo Viviani, he tried an experiment that changed the way people understood the air.

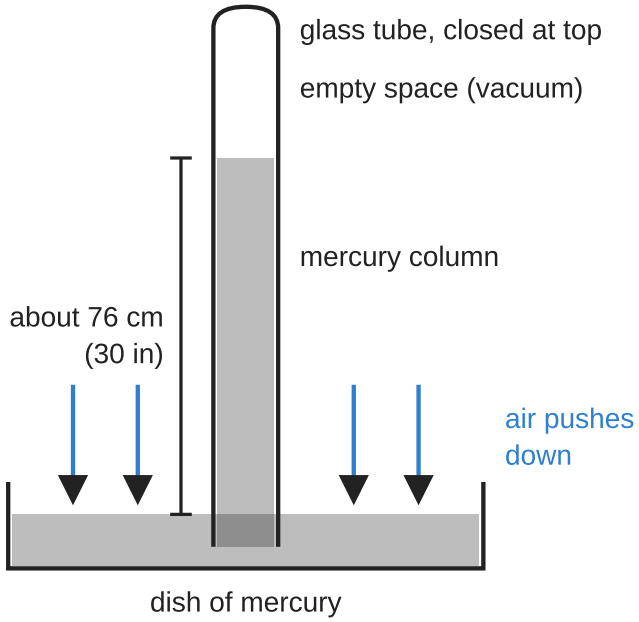
How they figured it out. Torricelli guessed that the pump was not really "sucking" the water up at all. Instead, he thought, the weight of the air outside was *pushing* on the water in the well and shoving it up the pipe. If that was true, a heavier liquid would be pushed up a shorter distance. So he chose **mercury**, a silvery liquid metal about 13 and a half times heavier than the same amount of water. He filled a glass tube about 1 meter (3 feet) long with mercury, closed at one end. He covered the open end, turned the tube upside down into a dish of mercury, and uncovered it. The mercury slid down the tube and then stopped, standing about 76 centimeters (30 inches) above the dish. At the top of the tube was an empty space with no air in it: a **vacuum**. Torricelli also noticed that the height of the mercury changed a little from day to day.

The big idea. Air has weight. Above our heads is a deep ocean of air called the **atmosphere**, many kilometers thick. Torricelli wrote to a friend that we live at the bottom of an ocean of air. All that air presses down on the mercury in the dish, and that push holds up the column in the tube. The push of the air is called **air pressure**. At the seashore, the air presses on every square centimeter about as hard as a 1-kilogram weight would (about 14.7 pounds on every square inch). We are not crushed because the air pushes on us from every side, and the air and water inside our bodies push back just as hard. Torricelli's tube was the first **barometer**, an instrument that measures air pressure.

Try it and see. You do not need mercury to see Torricelli's idea at work. When you held water in a straw with your finger, the air pushing up from below held the water in. When you lifted your finger, air could push from the top too, and the water fell. In this lesson you will fill a tall bottle with water and stand it upside down in a bowl. The water will stay up in the bottle, held there by the air pressing on the water in the bowl, just as the air held up Torricelli's mercury. If you had a clear tube more than 10 meters tall, the water would finally stop at about 10.3 meters (34 feet). That is the same limit the well-diggers of Florence ran into.

In the world today. Weather reporters in the United States still give air pressure in "inches of mercury," because of Torricelli's tube. A normal reading at sea level is about 29.92 inches (760 millimeters). Weather maps often use another unit called the **millibar**, and normal pressure is about 1013 millibars. Most barometers today use no mercury at all, because mercury is poisonous. You will build one of those safer barometers in the next lesson.

God's handiwork. Long before anyone weighed the air, the book of Job spoke of God making "the weight for the winds." The air is light enough for birds to fly through and for us to breathe without effort, yet all together it is heavy enough to hold up a column of metal as tall as a fourth grader's waist. God made our ocean of air just right for life, and Torricelli found a way to measure it.



Torricelli's barometer. The air pushing down on the dish holds up a column of mercury about 76 cm (30 in) tall.

PICTURE STUDY



An Experiment on a Bird in the Air Pump, Joseph Wright of Derby, 1768 · Oil on canvas · National Gallery, London

After Torricelli made the first vacuum, other scientists wanted to study empty space too. Otto von Guericke in Germany built an air pump in the 1650s, and Robert Boyle in England, with his helper Robert Hooke, built a better one. With a pump, they could take the air out of a glass globe and see what happened to a candle, a ringing bell or a living animal inside.

Joseph Wright of Derby was an English painter who loved candlelight and scenes of science. Here a traveling lecturer has pumped air out of a glass globe with a bird inside. Everyone at the table is learning, all at once, that living things need air. The lecturer's hand is on the top of the globe, ready to let the air back in.

Look closely

- Find the bird inside the glass globe at the top of the pump. How does it look?
- Find the lecturer's hand at the top of the globe. What could he do with it?
- Look at each face around the table. Who is curious, who is worried and who is thinking hard?
- Find the one candle that lights the room, and find the moon outside the window.

Talk about it

1. What does this experiment show about air, even though air is invisible?
2. Why do you think the painter made the room dark, with only one light?
3. If you were at the table, what question would you ask the lecturer?

> **Safety first.** Real mercury is poisonous. Never touch it, and never open or play with an old thermometer or barometer. Tell an adult right away if one breaks. This lesson uses only water. Do the bottle experiment over a sink, tub or tray, and let an adult make the pinhole.

EXPERIMENT: TORRICELLI'S WATER BOTTLE

You will repeat Torricelli's experiment with water instead of mercury. **Question:** Will water fall out of an upside-down bottle standing in a bowl of water? **Prediction:** Write what you think will happen before you start. **What we change:** whether air can get into the top of the bottle. **What we keep the same:** the bottle, the bowl and the amount of water. **What we measure:** the water level in the bottle, marked with tape, after one minute.

You will need

- A clear plastic bottle, about 1 liter (1 quart) or larger, with its label removed
- A wide bowl or baking dish
- Water (a few drops of food coloring help you see it)
- Masking tape and a marker
- A pushpin (for the adult only)
- Lab notebook and pencil

Steps

1. Fill the bowl about one-third full of water.
2. Fill the bottle all the way to the top with water.

3. Hold your palm flat over the mouth of the bottle, turn it upside down, and lower the mouth under the water in the bowl. Take your hand away while the mouth is under water.
4. Watch for one minute. Put a strip of tape on the bottle at the water level inside and mark it.
5. Record: Did the water fall out? Did any air get in?
6. Now have an adult push a pin through the bottom of the bottle (which is now at the top) and pull the pin out.
7. Watch again for one minute. Mark the new water level and record what happened.
8. Draw both trials side by side in your notebook, with arrows showing where the air is pushing.

Tips

- If a big bubble gets in, start again and keep the mouth of the bottle under water the whole time.
- Try a short glass and a tall bottle. In both, the water stays up, because air pressure could hold up water about 10 meters (34 feet) tall.
- When the pinhole lets air in at the top, the air pushes down from above just as hard as it pushes up from below, so gravity pulls the water out.

Check your work

- I wrote a prediction before I started.
- I marked and recorded the water level in both trials.
- I can explain that air pushing on the water in the bowl held the water up in the bottle.

FIELD NOTEBOOK

1. Draw Torricelli’s barometer: the tube, the dish, the mercury column, the empty space and arrows for the air. Label the height “about 76 cm (30 in).”
2. Draw yourself standing at the bottom of the “ocean of air,” with a tall stack of air above you reaching up into the sky.
3. Make a two-column chart called “Air Has Weight” and list three things you saw today that show air pushing.

> **From history.** The French thinker Blaise Pascal reasoned that if the air’s weight holds up the mercury, there should be less of that weight on a mountaintop. On September 19, 1648, his brother-in-law, Florin Périer, carried a mercury barometer up the Puy de Dôme, a mountain in central France, while a second barometer stayed in the town below. At the top the mercury stood about 8 centimeters (3 inches) lower, just as Pascal expected. Today one unit of pressure, the pascal, is named for him, and weather maps measure pressure in hectopascals, which are the same size as millibars.

WORKED EXAMPLES

Example 1. Mercury is about 13.6 times as heavy as the same amount of water. Air pressure holds up a column of mercury about 76 cm tall. About how tall a column of water could air pressure hold up? Use 14 to make a quick estimate, then compare with the real answer.

1. A liquid that is lighter is pushed up higher. Water is about 14 times lighter, so its column will be about 14 times taller.
2. Estimate: 76 cm × 14 = 760 cm + 304 cm = 1,064 cm.
3. Change to meters: 100 cm = 1 m, so 1,064 cm is about 10.6 m.
4. Using the more exact number, 76 cm × 13.6 = about 1,034 cm, or about 10.3 m (34 ft).

Answer: About 10 meters. The estimate gives about 10.6 m, and the real answer is about 10.3 m (34 ft), which is why the Florence pumps could not lift water any higher.

Example 2. In 1648, a barometer was read at the foot of a mountain in France and then carried to the top. At the bottom the mercury stood about 71 cm high. At the top it stood about 63 cm high. How much did it fall? What does that tell you?

1. Subtract the top reading from the bottom reading: 71 cm − 63 cm = 8 cm.
2. 8 cm is about 3 inches.
3. On the mountaintop there is less air above you, so there is less weight of air pushing down and the mercury column is shorter.

Answer: The mercury fell about 8 cm (3 in). Air pressure is lower high up, because there is less air above.

PRACTICE

1. EASY What liquid did Torricelli put in his tube, and why did he choose it instead of water?
2. EASY What was in the space at the top of Torricelli’s tube above the mercury?
3. MEDIUM Why didn’t all the mercury pour out of the tube into the dish?
4. MEDIUM Torricelli’s tube was about 100 cm long, and the mercury stood 76 cm high. How long was the empty space at the top?
5. MEDIUM Read the table. Barometer readings on the same morning: Seashore 76 cm; Hill town 71 cm; Mountain top 63 cm. (a) Which place is highest? (b) How much lower is the mountain-top reading than the seashore reading?
6. HARD Suppose you filled a glass tube only 50 cm long with mercury and turned it upside down in a dish, the way Torricelli did. What would happen? Explain.

7. HARD Experiment design: In the water bottle project, (a) what did you change between the two trials? (b) Name two things you kept the same. (c) What did you measure?
8. CHALLENGE Torricelli said we live at the bottom of an ocean of air. In two or three sentences, explain what he meant and why we are not crushed.

COMMON MISTAKES

- Thinking air weighs nothing. Air is light, but all the air above us together is very heavy and presses on everything.
- Thinking a straw or pump "sucks" liquid up. When you sip, you lower the pressure inside the straw, and the outside air pushes the drink up.
- Thinking the space at the top of Torricelli's tube was full of air. It was nearly empty, a vacuum; no air could get in.

> **Make it a game · Push or Pull?.** A parent names something that seems to "suck" or "pull," such as drinking through a straw, a suction cup on a window, a vacuum cleaner or a medicine dropper. You have ten seconds to explain where the air is really pushing. Score a point for each correct "air pushes" answer. Play to five points, then switch and quiz your parent.

> **Scripture.** "To make the weight for the winds; and he weigheth the waters by measure." (Job 28:25, KJV)

Job spoke of the weight of the wind thousands of years before Torricelli showed that air has weight. God made the air and set its weight, and Torricelli found a way to measure what God had made.

Practice answers

1. Mercury. It is so heavy (about 13.6 times heavier than water) that the air holds up only about 76 cm of it, so a tube about 1 m long was enough. Water would need a tube more than 10 m tall.
2. Almost nothing, not even air. It was a vacuum.
3. The weight of the air pressed down on the mercury in the dish. That air pressure pushed hard enough to hold up a column about 76 cm (30 in) tall.
4. 100 cm − 76 cm = 24 cm (about 9 or 10 inches).
5. (a) The mountain top, because it has the lowest reading (the least air above it). (b) 76 cm − 63 cm = 13 cm (about 5 inches).
6. The tube would stay completely full with no empty space at the top. Air pressure can hold up about 76 cm of mercury, so it easily holds up a 50 cm column.
7. (a) Whether air could get into the top of the bottle (no hole, then a pinhole). (b) Any two of: the same bottle, the same bowl, the same amount of water, the same one-minute wait. (c) The water level in the bottle, marked with tape.
8. Sample answer: The atmosphere is a deep layer of air above us, and its weight presses on us the way water presses on a diver at the bottom of a lake. We are not crushed because the air

pushes on us equally from every side, and the air and fluids inside our bodies push back just as hard.

2.2 Make a Barometer

OBJECTIVES

- Build a jar-and-balloon barometer and explain how its pointer shows rising and falling air pressure.
- Keep a daily barometer log for a week and compare it with the pressure in the weather report.
- Name one variable (temperature) that can fool a homemade barometer and plan how to control it.

Warm-up. Stretch a piece of plastic wrap tightly over the top of an empty bowl and hold it down with a rubber band. Press the middle gently with one finger and let go. Then hold the bowl in your two warm hands for a minute and watch the plastic. Talk about it: what might make a stretched “skin” move up or down by itself?

Video. Coming soon. How to make a homemade jar-and-balloon barometer and how aneroid barometers work: search NOAA SciJinks, NOAA National Weather Service education, SciShow Kids, Science Max and Homeschool Pop (Alternate) for kid-friendly builds and close-ups of dial barometers.

KEY TERMS

aneroid barometer
A barometer with no liquid in it. A sealed metal box gets squeezed in or puffs out as air pressure changes, and a needle shows the change.

millibar
A unit for air pressure used on weather maps. Normal sea-level pressure is about 1013 millibars (29.92 inches of mercury).

rising pressure
Air pressure going up over hours or days. It often means fair weather is coming.

falling pressure
Air pressure going down over hours or days. It often means clouds, rain or a storm are coming.

control
Something in an experiment that you keep the same so it does not change your results.

CORE IDEAS

The story. In the German city of Magdeburg lived a mayor and inventor named **Otto von Guericke**. He had read about Torricelli’s tube, and he built his own giant barometer using water instead of mercury. Since air pressure holds up about 10 meters (34 feet) of water, his tube ran up the outside wall of his house, several stories tall. On top of the water floated a

little wooden figure that pointed to marks as the water rose and fell. Neighbors called it his weather manikin. The story is told that in 1660 the water dropped unusually low, and Guericke warned that a great storm was coming. A few hours later, it did.

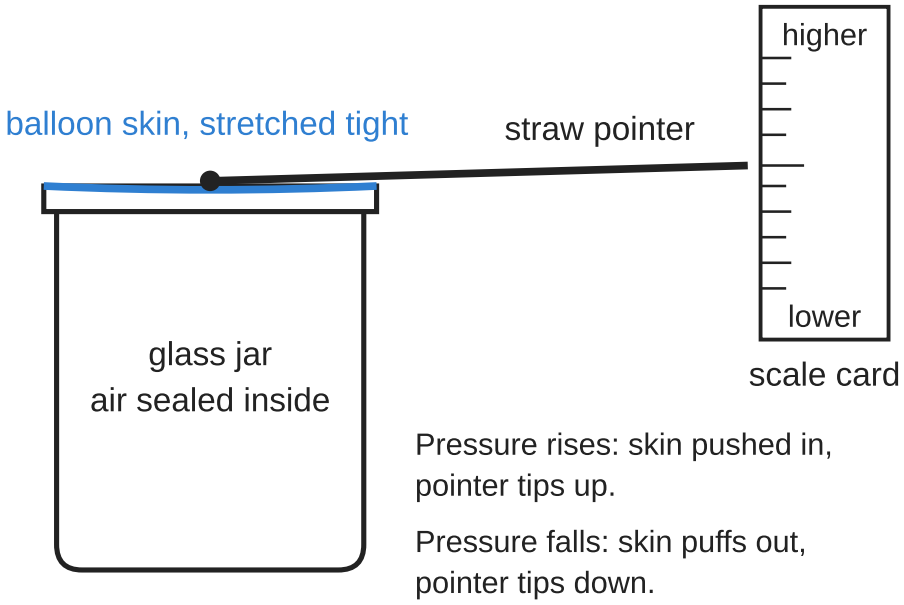
How they figured it out. Water barometers were too tall for most homes, and mercury barometers were heavy, easy to break and poisonous if they spilled. In 1844 a French inventor named **Lucien Vidie** made a barometer with no liquid at all. He called it an **aneroid barometer**, from Greek words meaning “without liquid.” Inside is a small, thin metal box with most of the air taken out. When the air pressure outside goes up, it squeezes the box in a tiny bit. When the pressure goes down, the box springs out a tiny bit. Little levers make that small motion big enough to turn a needle on a dial. Most barometers on walls today work this way.

The big idea. The jar barometer you will build works like Vidi’s box. You seal some air inside a jar under a stretched balloon skin. When the outside air pressure **rises**, it pushes harder on the skin than the air inside, so the skin dips in. When the outside pressure **falls**, the air inside pushes the skin up. A straw taped to the skin acts as a pointer. Because the straw rests on the rim of the jar like a seesaw, the far end tips *up* when the skin dips in, and tips *down* when the skin puffs up. So up on your scale means higher pressure, and down means lower pressure.

Try it and see. A barometer does not see the weather. It feels the air. What matters most is the *change*. Falling pressure often means clouds, rain or a storm are on the way. Rising pressure often means clearing skies. Steady pressure usually means the weather will stay much the same. Many old dial barometers have words printed on them, such as Stormy, Rain, Change, Fair and Very Dry, but a wise weather-watcher pays more attention to which way the needle is moving. Here is one catch: warm air inside your jar also puffs up the skin, and cool air lets it sink. So your jar must stay in one spot, out of the sun and away from heaters. Temperature is a variable you must **control**.

In the world today. Weather stations all over the country read air pressure every hour. Your local weather report might say “30.05 inches and rising” or show “1018 millibars” on a map. Air pressure also drops as you go higher, about 1 millibar for every 8 meters (26 feet) near the ground. Airplanes use this fact: an **altimeter** is a barometer that shows height instead of weather. A hiker carrying a barometer up a mountain watches it fall with every step.

God’s handiwork. The air over your house is never still. It grows heavier and lighter as great masses of air move across the land, and God gave people the minds to notice it, measure it and make wise plans. A farmer who sees the barometer falling brings in the hay. A sailor heads for harbor. Learning to read the sky and the barometer is one way we use the good gift of reason God has given us.



A jar barometer. When outside pressure rises, the skin is pushed in and the pointer tips up. When pressure falls, the skin puffs out and the pointer tips down.

PICTURE STUDY



Wanderer above the Sea of Fog, Caspar David Friedrich, about 1818 · Oil on canvas · Hamburger Kunsthalle, Hamburg, Germany

Caspar David Friedrich was a German painter who loved mountains, mists and wide skies. In this painting a traveler has climbed to the top of a rocky peak. Below him, fog fills the valleys, and only the tops of rocks and far-off mountains poke through.

If the traveler had carried a barometer up the mountain, he would have watched it fall the whole way. Up high there is less air above him, so the air pressure is lower. That is why the mountaintop barometer in Pascal's experiment read lower than the one in town.

Look closely

- Find the traveler. Where is he standing, and where is he looking?
- Find the fog. Is it above him or below him?
- Find three rocky tops that poke up through the fog.
- Look at the sky. Does it look like stormy weather or calm weather?

Talk about it

1. Would a barometer read higher in the valley or on the peak? Why?
2. Why do you think Friedrich painted the traveler with his back to us?
3. What would you want to write in your weather notebook if you stood where he is?

> **Safety first.** An adult should handle the scissors when cutting the balloon. Use a sturdy jar and work on a table so it cannot fall and break. Keep balloon scraps away from small children, who could choke on them. If anyone in your family has a latex allergy, use plastic wrap instead of a balloon.

EXPERIMENT: MY JAR BAROMETER AND WEATHER LOG

You will build a barometer and use it for one week. **Question:** Does my jar barometer rise and fall along with the real air pressure in the weather report? **Prediction:** Write what you expect. **What changes:** the outside air pressure (you do not control it; you watch it). **What we keep the same:** the jar's spot, the temperature of the room and the time of day you read it. **What we measure:** where the pointer sits on the card, in millimeters, and the official pressure from the weather report.

You will need

- A clean, wide-mouth glass jar
- One large balloon
- Scissors (adult use)
- A strong rubber band
- A drinking straw
- Tape or a drop of glue
- An index card, a ruler and a pencil
- A box or stack of books to hold the card upright
- Lab notebook

Steps

1. Have an adult cut the neck off the balloon. Stretch the round part tightly over the jar’s mouth and hold it in place with the rubber band. It should be flat and tight like a drum.
2. Tape one end of the straw to the center of the balloon skin, so the straw lies across the rim and sticks out past the edge of the jar.
3. Stand the index card upright beside the jar, close to the end of the straw. Tape it to a box or book so it cannot move.
4. Mark where the straw points. Then use a ruler to draw small tick marks every 2 millimeters above and below it. Label the top “higher” and the bottom “lower.”
5. Put the jar in a room that stays about the same temperature, away from sunny windows, heaters and air vents. Do not move it again.
6. Every day at the same time, read the pointer. Record the date, the pointer position (how many millimeters above or below your first mark), the sky and the official pressure from a weather report.
7. At the end of the week, make a bar graph of your pointer readings. Compare it with the official pressures. Did they go up and down on the same days?

Tips

- The pointer moves only a little. Look straight at it at eye level each time so you read it the same way.
- If the pointer moves a lot during one day and back again at night, the room temperature may be changing. Move the jar to a steadier spot and start over.
- Your barometer shows changes, not exact millibars. That is fine: changes are what forecasters watch most.

Check your work

- My jar is sealed tightly and the straw points to a marked scale.
- I recorded seven days of readings at the same time each day.
- I can explain why the pointer goes up when the pressure rises and why I kept the jar out of the sun.

FIELD NOTEBOOK

1. Draw your jar barometer and label the jar, the balloon skin, the straw pointer and the scale card.
2. Draw two small pictures of the balloon skin side by side: one on a high-pressure day (skin pushed in) and one on a low-pressure day (skin puffed up). Add arrows for the air.
3. Copy your week of readings into a neat table and write one sentence about what the barometer did before a rainy or cloudy day.

> **From history.** Otto von Guericke also built one of the first air pumps. In 1654 at Regensburg, before Emperor Ferdinand III, he fitted two large copper half-spheres together and pumped the air out from inside. Teams of horses pulled on the two halves in opposite directions and could not pull them apart. Then Guericke opened a valve to let air

> back in, and the halves fell apart by themselves. He repeated the show later in Magdeburg, and the two halves became famous as the Magdeburg hemispheres. Nothing was holding them together except the push of the air outside.

WORKED EXAMPLES

Example 1. Lily recorded her jar barometer pointer in millimeters above her first mark: Monday 12, Tuesday 14, Wednesday 15, Thursday 9, Friday 6. Between which two days did the pointer drop the most? What weather might Lily have expected?

1. Find each change: Mon to Tue 12 → 14, up 2 mm. Tue to Wed 14 → 15, up 1 mm. Wed to Thu 15 → 9, down 6 mm. Thu to Fri 9 → 6, down 3 mm.
2. The biggest drop is 6 mm, from Wednesday to Thursday.
3. A pointer moving down means the air pressure is falling. Falling pressure often brings clouds and rain.

Answer: Wednesday to Thursday (down 6 mm). The pressure was falling, so Lily could expect clouds, rain or a storm.

Example 2. The weather report gave the pressure as 1022 millibars on Monday and 1004 millibars on Thursday. How much did the pressure change? On average, how much did it change each day?

1. Subtract: 1022 − 1004 = 18 millibars.
2. The pressure went down, so it fell 18 millibars.
3. Monday to Thursday is 3 days. 18 ÷ 3 = 6 millibars per day.

Answer: It fell 18 millibars, about 6 millibars per day. Falling pressure like this often brings stormy weather.

PRACTICE

1. EASY What does a barometer measure?
2. EASY Your jar barometer’s pointer moves up. Is the air pressure rising or falling? What kind of weather often follows?
3. EASY What does the word aneroid mean, and who invented the aneroid barometer?
4. MEDIUM Explain why the end of the straw tips up when the balloon skin is pushed in.
5. MEDIUM Read the table of official pressures: Sunday 1016 mb, Monday 1011 mb, Tuesday 1003 mb, Wednesday 1009 mb, Thursday 1019 mb. (a) Which day had the lowest pressure? (b) Was the pressure rising or falling from Tuesday to Thursday, and by how much? (c) Which day was most likely stormy?
6. MEDIUM Guericke’s weather manikin floated on top of a column of water. Why did he need such a tall tube, running up the side of his house?

7. HARD Experiment design: Sam put his jar barometer on a sunny windowsill. Every afternoon the pointer dropped, and every morning it rose again. (a) What variable is fooling his barometer? (b) How should he fix his experiment?
8. CHALLENGE Near the ground, air pressure drops about 1 millibar for every 8 meters you go up. You ride an elevator 40 meters up a tall building. About how much would a barometer fall? Why does it fall?

COMMON MISTAKES

- Thinking a barometer measures temperature or wind. It measures air pressure; a thermometer measures temperature.
- Thinking the word on a dial (Rain, Fair) is the forecast. The direction the needle is moving, rising or falling, matters more.
- Thinking a homemade jar barometer feels only air pressure. Warming and cooling of the air inside also move the skin, so temperature must be kept the same.

Make it a game · Barometer Charades. One player is the barometer. A parent calls out a weather change, such as “a storm is coming,” “the sky is clearing” or “nothing is changing.” The barometer must act it out: stand on tiptoe for rising pressure, crouch down slowly for falling pressure, or stand still for steady. Then the parent calls out a pressure change, such as “1020 millibars and rising,” and the player must name the likely weather. One point for each right answer.

Scripture. “Fair weather cometh out of the north: with God is terrible majesty.” (Job 37:22, KJV)

Elihu tells Job to stand still and consider the works of God in the weather. Watching a barometer is one way to consider them carefully, day after day, and to remember that the One who sends fair weather and storms is great in majesty.

Practice answers

1. Air pressure.
2. Rising. Rising pressure often brings fair, clearing weather.
3. It means “without liquid.” Lucien Vidie of France invented it in 1844.
4. The straw rests on the jar’s rim like a seesaw. When the end taped to the middle of the skin goes down, the other end on the far side of the rim goes up.
5. (a) Tuesday, 1003 mb. (b) Rising, by 1019 − 1003 = 16 mb. (c) Tuesday, at the lowest pressure after two days of falling.
6. Air pressure can hold up about 10 meters (34 feet) of water, because water is much lighter than mercury. The tube had to be taller than that for the water to have room to rise and fall.
7. (a) Temperature. The sun warms the air in the jar in the afternoon, so it puffs up the skin and the pointer drops; at night it cools and the pointer rises. (b) Move the jar to a spot that stays the same temperature, out of the sun and away from heaters, and read it at the same time each day. Temperature becomes a control.

8. 40 ÷ 8 = 5, so about 5 millibars. It falls because there is less air above you up high, so less weight of air is pressing down.

2.3 Hot Air Rises

OBJECTIVES

- Tell how the Montgolfier brothers sent up the first hot-air balloons in 1783.
- Explain that warm air expands and becomes less dense, so cooler, heavier air sinks and pushes it up (convection).
- Do an experiment with warm and cold colored water, and describe how a sea breeze forms.

Warm-up. Ask an adult to pour a mug of hot tap water (not boiling). Hold your open hand about a hand-width *above* the mug for ten seconds. Then hold it the same distance *beside* the mug. Where did your hand feel warmer? Talk about it: which way does the warm air from the mug seem to travel?

Video. Coming soon. Hot air rises, convection and sea breezes for kids, plus the Montgolfier brothers' first hot-air balloon: search NOAA SciJinks, NASA, SciShow Kids, Science Max, Homeschool Pop (Alternate) and hot-air balloon festival footage.

KEY TERMS

expand
To spread out and take up more space. Air expands when it is warmed.

contract
To shrink and take up less space. Air contracts when it is cooled.

density
How much matter is packed into a space. Warm air is less dense than cold air, so the same space of warm air weighs less.

convection
The rising of warm air or water and the sinking of cool air or water, which carries heat from place to place.

sea breeze
A cool wind that blows from the sea onto the land on a sunny day, because the warm air over the land rises.

CORE IDEAS

The story. In the town of Annonay in southern France, two brothers named **Joseph-Michel and Jacques-Étienne Montgolfier** ran their family's paper factory. A family story says Joseph watched bits of cloth and ash float up over a fire and began to wonder. The brothers made small bags of paper and cloth and held them over flames. The bags filled up and rose! On June 4, 1783, in the town square of Annonay, they built a fire of straw and wool under a huge balloon of cloth lined with paper. The balloon rose high into the sky and came down

more than a mile away. That September, at the palace of Versailles, they sent up a balloon carrying a sheep, a duck and a rooster while King Louis XVI watched. The animals landed safely.

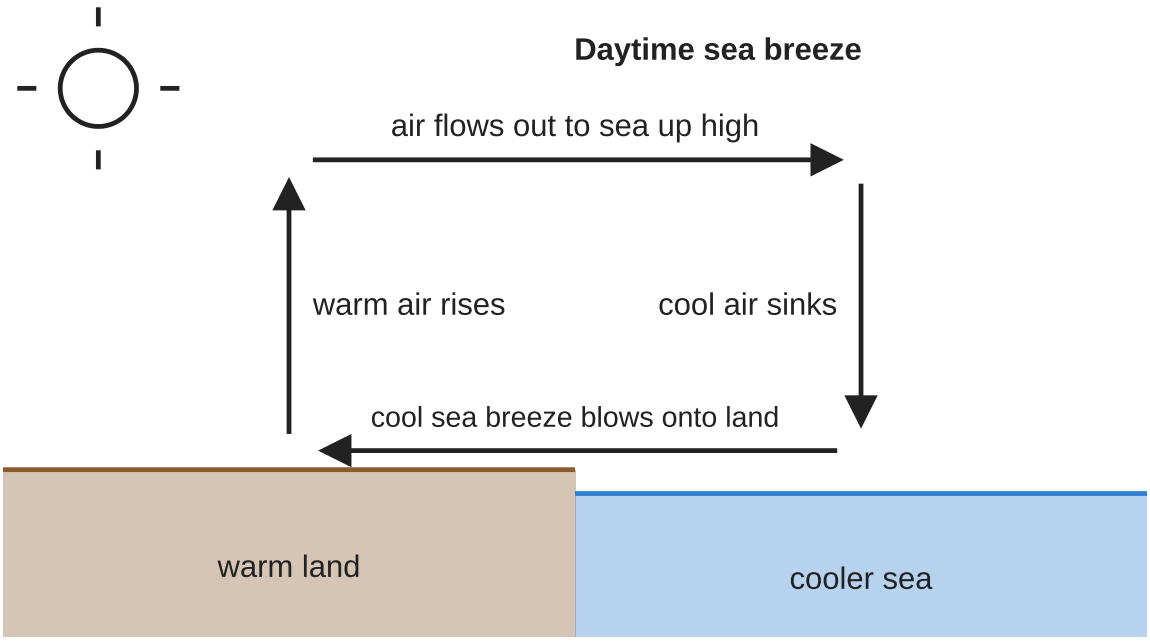
How they figured it out. At first the Montgolfiers thought the smoke from burning straw and wool must be a special lifting gas. They even chose smoky fuels on purpose. But other scientists soon showed that smoke had nothing to do with it. The secret was *heat*. When air is warmed, it **expands**, spreading out to fill more space. The same amount of air now takes up more room, so a balloon full of hot air weighs less than the same balloon full of cool air. Today's hot-air balloons use clean propane burners, and they fly because the air inside is hot, not because it is smoky.

The big idea. Scientists say warm air is less **dense** than cool air: less matter is packed into each bit of space. A cubic meter of air at room temperature weighs about 1.2 kilograms (more than 2.5 pounds). Heat it up, and the same space holds less air, so it weighs less. Cooler, heavier air sinks underneath and pushes the warm air up, the way water pushes a cork to the top of a bucket. Then the warm air cools, grows denser and sinks again. This loop of rising and sinking is called **convection**. It is why the top of a room is warmer than the floor, why smoke goes up a chimney, and why hawks can circle higher and higher on rising warm air without flapping.

Try it and see. Convection works in water too, because warm water is also less dense than cold water. In this lesson you will lower a small jar of warm, colored water into a big container of cold water, and a jar of cold, colored water into another. You will see one color climb like smoke and the other stay low. You are watching the same push that lifted the Montgolfier balloon.

In the world today. On a sunny day at the beach, the sand and land heat up faster than the sea. The air over the land grows warm and rises. Cooler air from over the water slides in underneath to take its place, and you feel a cool **sea breeze**. Up high, the air flows back out over the sea and sinks, completing the loop. Rising air also makes clouds. As warm air rises, it expands and cools, and its water vapor can condense into the tall, puffy clouds of a summer afternoon. That is why it is usually colder on a mountaintop, even though hot air rises. In the next lesson you will see how rising and sinking air make the highs and lows on a weather map.

God's handiwork. Convection is one of the ways God keeps the world's air moving. Sunshine warms the ground, the warm air rises, and cooler air flows in. The same simple rule carries warm air and water vapor up into the sky, brings cool breezes to the shore, and lifts soaring birds. The psalmist praised the God who "causeth the vapours to ascend from the ends of the earth."



A daytime sea breeze is a convection loop. Warm air rises over the land, and cool air from the sea flows in to take its place.

PICTURE STUDY



The Fighting Temeraire Tugged to Her Last Berth to Be Broken Up, J. M. W. Turner, 1839 · Oil on canvas · National Gallery, London

The *Temeraire* was a great wooden warship that fought in the Battle of Trafalgar in 1805. In 1838 she was old and worn out, and a small steam tugboat towed her up the River Thames to be taken apart. The English painter J. M. W. Turner painted the scene the next year, with the old ship glowing pale like a ghost and the busy little tug leading the way.

Look closely at the tug’s tall smokestack. A fire in the tug’s boiler heats air and smoke, and that hot air rises up the stack and out the top, pulling fresh air in below to keep the fire burning. Every chimney works by convection.

Look closely

- Find the tug’s smokestack. Which way does the smoke go first as it leaves the top?
- Find the old warship. How is she different from the tug in color and shape?
- Find the setting sun. What colors did Turner use for the sky and its reflection on the water?
- Look at the water. Is it calm or rough? What does that tell you about the wind?

Talk about it

1. Why does smoke rise out of the smokestack instead of sinking to the water?
2. Why do you think Turner made the old ship pale and the tug dark?
3. What other things have you seen rise because they were warm?

> **Safety first.** An adult should pour and handle all hot water. Use hot tap water only, never boiling water. Use sturdy jars, work on a tray to catch spills, and wipe up water on the floor right away. Never put a flame inside or under a balloon or paper bag.

EXPERIMENT: THE WARM AND COLD WATER RACE

You will see convection in water. **Question:** Does warm water rise or sink in cold water? Does cold water rise or sink? **Prediction:** Write what you think each color will do. **What we change:** the temperature of the water in the small jar (warm or cold). **What we keep the same:** the size of the small jar, the amount of water in it, the number of drops of food coloring, and the cold water in the big container. **What we measure:** whether the color rises or sinks, and how many seconds it takes to reach the top (if it does).

You will need

- Two large clear containers (glass baking dishes, big jars or a clean fish tank)
- Cold tap water with a few ice cubes (remove the ice before you start)
- Two small jars or bottles of the same size
- Hot tap water (adult pours)
- Red and blue food coloring
- A kitchen thermometer, if you have one
- A timer or clock with a second hand
- Lab notebook and colored pencils

Steps

1. Fill both large containers with cold water and let them sit for a minute until the water is still. If you have a thermometer, record the temperature.

2. Have an adult fill one small jar with hot tap water. Add 3 drops of red coloring. Record its temperature if you can.
3. Fill the other small jar with very cold water and add 3 drops of blue coloring.
4. Hold the red jar upright and slowly lower it to the bottom of the first container. Start the timer and watch.
5. Record what the red water does and how many seconds it takes to reach the top.
6. Lower the blue jar slowly into the second container in the same way. Record what the blue water does.
7. Draw both containers with arrows showing which way each color moved.
8. Write a conclusion: Was your prediction right? Use the words warm, cold, dense and rise or sink.

Tips

- Lower the jars very slowly so you do not stir the water yourself.
- Watch the red water spread out at the top and then slowly sink as it cools. That is a convection loop!
- Extra test: lay the red jar on its side at the bottom. Does the color still go up?

Check your work

- I wrote a prediction and kept the jar size, amount of water and drops of coloring the same.
- I recorded what each color did and how long the warm color took to rise.
- I can explain that warm water is less dense, so the cold water around it pushes it up.

FIELD NOTEBOOK

1. Draw the Montgolfier balloon over its fire, with arrows showing hot air going in and up.
2. Draw a room in your house with a thermometer near the floor and one near the ceiling, and write which you think would read warmer.
3. Draw the sea breeze loop: warm land, cool sea, and four arrows going around. Label “warm air rises” and “cool air sinks.”

> **From history.** On November 21, 1783, two Frenchmen, Jean-François Pilâtre de Rozier and the Marquis d’Arlandes, became the first people to fly freely in a balloon. They rose in a Montgolfier hot-air balloon from the edge of Paris, fed the fire with straw as they went, and drifted across the city for about 25 minutes before landing safely several miles away. Among the crowd of watchers was Benjamin Franklin, who was living in Paris as the American representative to France. He wrote letters home describing the new flying machines with great excitement.

WORKED EXAMPLES

Example 1. On a winter evening, a family hung one thermometer near the floor of the living room and one near the ceiling. The floor thermometer read 19°C (66°F). The ceiling thermometer read 24°C (75°F). How much warmer was it at the ceiling? Why?

1. Subtract in Celsius: 24°C − 19°C = 5°C.
2. Subtract in Fahrenheit: 75°F − 66°F = 9°F.
3. Warm air from the heater is less dense, so cooler air sinks under it and pushes it up toward the ceiling.

Answer: It was 5°C (9°F) warmer at the ceiling, because warm air rises and cool air sinks.

Example 2. When air inside a hot-air balloon is heated to about 100°C (212°F), each cubic meter of it can lift about 250 grams (a quarter of a kilogram). A small balloon holds 2,000 cubic meters of hot air. About how much can it lift?

1. Lift per cubic meter: about 250 g, which is ¼ kg.
2. Total lift: 2,000 × ¼ kg = 500 kg.
3. In pounds: 500 kg × 2.2 = 1,100 lb.
4. That lift must carry the balloon cloth, the basket, the burner and fuel as well as the people.

Answer: About 500 kg (1,100 lb) of lift for the balloon, basket, burner and riders together.

PRACTICE

1. EASY Who sent up the first hot-air balloons, and in what year?
2. EASY What happens to air when it is warmed: does it expand or contract?
3. MEDIUM The Montgolfiers thought smoke lifted their balloon. What really made it rise?
4. MEDIUM Read the table of temperatures measured in one room: Floor 18°C; 1 meter up 20°C; 2 meters up 22°C; Ceiling (2.5 meters up) 23°C. (a) Describe the pattern. (b) How much warmer is the ceiling than the floor?
5. MEDIUM A cubic meter of room-temperature air weighs about 1.2 kg. A bedroom holds about 30 cubic meters of air. About how much does the air in the bedroom weigh?
6. HARD Experiment design: In the warm and cold water race, (a) what was the one thing you changed? (b) Name two things you kept the same. (c) Why does it matter to keep them the same?
7. HARD Explain in two or three sentences why a cool sea breeze blows onto the beach on a sunny afternoon.

8. CHALLENGE If hot air rises, why is it usually colder on top of a high mountain than at the bottom?

COMMON MISTAKES

- Saying “heat rises.” Heat moves in every direction; it is *warm air* (or warm water) that rises, because cooler, denser air sinks and pushes it up.
- Thinking smoke or a special gas lifts a hot-air balloon. The Montgolfiers thought so too, but it is the heat that makes the air inside less dense.
- Thinking that because hot air rises, mountaintops must be warm. Rising air expands and cools, so high places are usually colder.

Make it a game · Rise or Sink?. A parent names something: a hot-air balloon, an ice cube in a glass of water, smoke from a campfire, cold air from an open freezer, steam from a pot, a bubble in a fish tank. Stand up tall for “rises” or crouch down for “sinks,” then say why in one sentence using the word “dense.” Score a point for each right move and reason. First to six points wins.

Scripture. “He causeth the vapours to ascend from the ends of the earth; he maketh lightnings for the rain; he bringeth the wind out of his treasuries.” (Psalm 135:7, KJV)

Rising warm air carries water vapor up into the sky, where it forms clouds and rain, and moving air becomes the wind. The psalmist saw the hand of God in every part of it.

Practice answers

1. The Montgolfier brothers, Joseph-Michel and Jacques-Étienne, of France, in 1783.
2. It expands; it spreads out and takes up more space.
3. Heat. The hot air inside expanded and became less dense (lighter for its size) than the cooler air outside, so the cooler air pushed the balloon up.
4. (a) The higher the thermometer, the warmer the air, because warm air rises. (b) 23°C − 18°C = 5°C.
5. 30 × 1.2 kg = 36 kg (about 79 lb), about as heavy as a fourth grader.
6. (a) The temperature of the water in the small jar. (b) Any two of: the jar size, the amount of water, the number of drops of coloring, the cold water in the big container, lowering the jar slowly. (c) So that if the colors behave differently, we know it was caused by the temperature and not by something else.
7. The sun heats the land faster than the water, so the air over the land gets warm and rises. Cooler, denser air over the sea flows in underneath to take its place. That moving cool air is the sea breeze.
8. Rising air expands as the air pressure around it gets lower, and air that expands cools down. So even though warm air rises from the ground, it cools as it goes up, and mountaintops are usually colder.

2.4 Highs and Lows on a Map

OBJECTIVES

- Explain that air sinks in a high-pressure area, bringing fair weather, and rises in a low-pressure area, bringing clouds and rain.
- Read H, L and isobars on a weather map, and tell where winds are strongest.
- Use Buys Ballot's law and a week of pressure records to find where the low pressure lies.

Warm-up. Blow up a balloon, pinch the neck, and then let a little air hiss out against your hand. Which way did the air go: from the squeezed air inside the balloon to the outside, or the other way? Talk about it: air always tries to move from where it is crowded to where it is less crowded.

Video. Coming soon. High and low pressure systems, isobars and reading a weather map for kids: search NOAA SciJinks, NOAA National Weather Service JetStream, NASA, SciShow Kids, Homeschool Pop (Alternate) and TV-meteorologist explainer clips.

KEY TERMS

high-pressure area (high)
A large area where air pressure is higher than around it. The air sinks, and the weather is usually fair. Marked H on a map.

low-pressure area (low)
A large area where air pressure is lower than around it. The air rises, and clouds and rain often form. Marked L on a map.

isobar
A line on a weather map that connects places with the same air pressure.

wind
Air moving across the earth's surface, mostly from higher pressure toward lower pressure.

Buys Ballot's law
In the Northern Hemisphere, if you stand with your back to the wind, the low pressure is on your left.

CORE IDEAS

The story. In the Dutch city of Utrecht lived a scientist named **Christophorus Buys Ballot**. In 1854 he became the first director of the new weather institute of the Netherlands, and he set up stations to read barometers and wind vanes across the country. Comparing all those readings, he found a simple rule. In 1857 he announced it: in our half of the world, if you stand with your back to the wind, the lowest air pressure lies on your left hand. Sailors and weather watchers have used **Buys Ballot's law** ever since to find where a storm is.

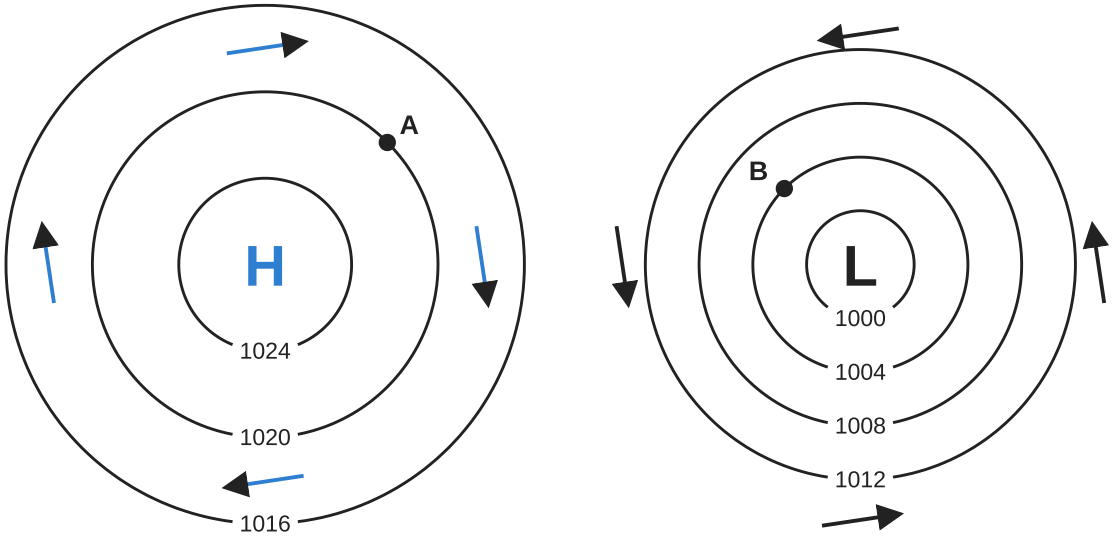
How they figured it out. Buys Ballot could see the pattern only because many people wrote down barometer readings at the same time in different places. When the numbers were put on a map, places with the same pressure could be joined with a line, like connecting dots. These lines are called **isobars** (from Greek words meaning “equal weight”). The isobars made rings around a few spots with the highest pressure and a few with the lowest. Today forecasters mark these spots with a big **H** for high pressure and a big **L** for low pressure. On American TV maps the H is often blue and the L is often red.

The big idea. In a **high**, cool air is sinking slowly from above. Sinking air warms a little and dries out, so clouds fade away. Highs usually bring clear skies and calm or gentle winds. In a **low**, air is rising, as warm air does. Rising air cools, and its water vapor condenses into clouds, so lows often bring clouds, rain, snow and storms. Air near the ground flows out of a high and into a low, and that moving air is **wind**. Because the earth is spinning, the wind does not blow straight across. In the Northern Hemisphere it curls *clockwise* and outward around a high, and *counterclockwise* and inward around a low. Where the isobars are packed close together, the pressure changes quickly over a short distance, and the wind is strong.

Try it and see. Look at the map in this lesson. Town A is near the high, and Town B is near the low. Count the isobars between them. Notice that the rings around the L are closer together than the rings around the H. Now go outside on a breezy day and stand with your back to the wind. Point your left arm out a little forward. That is the direction of the nearest low. Check your barometer log too: when a low moves toward you, your barometer falls.

In the world today. The National Weather Service draws a new surface map every few hours from thousands of readings taken by weather stations, ships, buoys and airports. You can look at it yourself online. Highs and lows usually drift across the United States from west to east, so a forecaster who sees a low over the Rocky Mountains may warn that rain will reach the eastern states a few days later. Highs often read around 1020 to 1040 millibars, and lows often read around 980 to 1005 millibars. The strongest storms, hurricanes, have some of the lowest pressures ever measured.

God’s handiwork. Long ago, the Preacher in Ecclesiastes noticed that the wind goes round and round in circuits. Today we can draw those circuits on a map, spinning around the highs and the lows. The winds move water vapor over the land, bring rain to fields far from the sea and carry it away again, all by the orderly laws God set in place.



Isobars every 4 millibars. Arrows show winds in the Northern Hemisphere.

Isobars around a high (H) and a low (L), drawn every 4 millibars. Winds curl clockwise out of the high and counterclockwise into the low (Northern Hemisphere).

PICTURE STUDY



The Hay Wain, John Constable, 1821 · Oil on canvas · National Gallery, London

John Constable grew up in the English countryside of Suffolk, where his father owned mills, including windmills. As a young man Constable worked for his father, and a miller has to watch the wind and the sky every day. When he became a painter, he kept watching the weather and painted skies with great care.

In this painting a hay wain, which is a farm wagon for carrying hay, has rolled into the shallow River Stour, near a cottage Constable knew well. Farm workers are cutting hay in the sunny meadow far behind. Haymaking needs several dry days in a row, the kind of weather that a high-pressure area often brings.

Look closely

- Find the clouds. Are they flat and gray all over, or puffy with patches of blue between?
- Find the patches of sunlight and shadow on the meadow in the distance.
- Find the dog on the riverbank. What is it looking at?
- Find the wagon’s wheels. Why might the driver have rolled the wagon into the water?

Talk about it

1. Does this look like weather under a high or a low? What clues tell you?
2. If you were the farmer, what would you want your barometer to be doing during haymaking?
3. How much of the painting is sky? Why do you think Constable gave the sky so much room?

EXPERIMENT: PRESSURE MAP AND WEATHER WATCH

First you will draw isobars on a map of pretend weather stations. Then you will watch the real air pressure and the sky for a week. **Question:** Does falling pressure come before cloudy or rainy weather where I live? **Prediction:** Write what you expect. **What we measure:** the pressure each day (from your jar barometer and from a weather report), whether it rose or fell, and the sky and rain. **What we keep the same:** the time of day and the source of the official reading.

You will need

- A sheet of paper, a pencil and colored pencils
- A ruler
- Your jar barometer from Lesson 2.2
- A weather report with air pressure (newspaper, radio or the National Weather Service website, with a parent)
- Lab notebook

Steps

1. Part A. Draw a large rectangle for your map. Write these station numbers spread out across it: in the left half 1024, 1022, 1020, 1020, 1018, 1016; in the right half 1014, 1012, 1010, 1008, 1006, 1004. Put the highest numbers near the left side and the lowest near the right side.
2. Draw a smooth line connecting all the places with 1020, guessing in between stations. Then draw lines for 1016, 1012 and 1008.

3. Write a blue H where the pressure is highest and a red L where it is lowest. Draw a few curved wind arrows: clockwise and out of the H, counterclockwise and into the L.
4. Part B. Make a table with columns: Date, Official pressure, Rising or falling, Jar pointer, Sky, Rain? Wind from.
5. Every day for a week at the same time, fill in one row. Check the wind with a ribbon or by watching flags and trees.
6. Once during the week, stand with your back to the wind and point to where the low should be. Write which direction you pointed.
7. At the end, circle the days the pressure fell. Write two sentences: Did clouds or rain follow falling pressure? Did fair weather follow rising pressure?

Tips

- Isobars never cross each other, and each one either makes a closed loop or runs off the edge of the map.
- One week is a short time. If the weather stays the same all week, that is a real result too: steady pressure, steady weather.
- Compare your hand-drawn map with the real surface map from the National Weather Service. Can you find an H and an L?

Check your work

- My map has at least three isobars, an H, an L and curved wind arrows going the right way.
- I recorded seven days of pressure and weather at the same time each day.
- I can explain what weather highs and lows usually bring and why.

FIELD NOTEBOOK

1. Draw a high and a low side by side as seen from the side: arrows sinking down in the high under a clear sky, and arrows rising up in the low into a cloud.
2. Copy the map from this lesson and label H, L, two isobars with their numbers, and the place where the wind is strongest.
3. Draw yourself standing with your back to the wind, with an arrow from your left hand pointing to an L.

> **From history.** Before his famous weather law, Buys Ballot did another clever experiment. In 1845 he put a group of trumpet players on an open railway car near Utrecht and had them hold one steady note as the train rushed past musicians standing beside the track. The listeners heard the note sound higher as the train came toward them and lower as it went away. This tested an idea published a few years earlier by the Austrian scientist Christian Doppler. Today weather radar uses that same Doppler effect, with radio waves instead of trumpet notes, to see which way the wind is blowing inside a storm.

WORKED EXAMPLES

Example 1. Use the map in this lesson. (a) What is the pressure at Town A and at Town B? (b) How big is the difference? (c) Which town probably has fair weather, and which has clouds? (d) Where is the wind strongest?

(Use the map or drawing "Use the labeled isobars to read the pressure at each town." shown earlier in this lesson.)

1. Town A sits on the isobar labeled 1020, so its pressure is 1020 millibars. Town B sits on the isobar labeled 1004, so its pressure is 1004 millibars.
2. Difference: $1020 - 1004 = 16$ millibars.
3. Town A is near the H, where air sinks and skies clear. Town B is near the L, where air rises and clouds form.
4. The isobars around the L are closer together than those around the H, so the wind is strongest around the low.

Answer: (a) Town A 1020 mb, Town B 1004 mb. (b) 16 millibars. (c) Town A probably has fair weather; Town B probably has clouds or rain. (d) Around the low, where the isobars are closest.

Example 2. City X reports 1030 millibars and City Y reports 1006 millibars. A forecaster draws isobars every 4 millibars (1008, 1012, 1016 and so on). How many isobars lie between the two cities? Which city is closer to a high?

1. List the isobar values between 1006 and 1030 that are multiples of 4: 1008, 1012, 1016, 1020, 1024, 1028.
2. Count them: 6 isobars.
3. Check: the difference is $1030 - 1006 = 24$ millibars, and $24 \div 4 = 6$.
4. The higher pressure, 1030, is at City X.

Answer: 6 isobars lie between them. City X (1030 mb) is closer to a high.

PRACTICE

1. EASY What do the letters H and L stand for on a weather map?
2. EASY What is an isobar?
3. MEDIUM Is air rising or sinking in a low? What weather does that usually bring?
4. MEDIUM In the Northern Hemisphere, which way does the wind curl around a high, and which way around a low?
5. MEDIUM Read the table of pressures at noon: Denver 1026 mb; Omaha 1018 mb; Chicago 1009 mb; Detroit 1001 mb; Cleveland 1006 mb. (a) Which city is nearest the center of the low? (b) Which is nearest the high? (c) What is the difference between them?

6. HARD On one map the isobars over Ohio are far apart, and the isobars over Texas are packed close together. Where would you expect stronger winds? Why?
7. HARD Experiment design: Maria wants to find out whether falling pressure comes before rain at her house. (a) What should she measure each day? (b) Name two things she should keep the same. (c) Why should she record for many days instead of just two?
8. CHALLENGE You live in the Northern Hemisphere. A wind is blowing from the south against your back, so you are facing north. Using Buys Ballot's law, in which direction is the low pressure?

COMMON MISTAKES

- Thinking H means hot and L means cold. H and L mean high and low air pressure; a high can be cold in winter, and a low can be warm.
- Thinking wind blows straight from the H to the L. Because the earth spins, winds curl around highs and lows.
- Thinking isobars are roads, borders or rivers. They are imaginary lines joining places with equal air pressure.

Make it a game · Spin the Pressure. Draw a big H and a big L in chalk on the driveway or on two sheets of paper on the floor. A parent calls out a weather clue, such as "sunny and calm," "rain and gusty wind," "barometer falling" or "air sinking." Run to the H or the L. Then walk one circle around it the right way: clockwise and outward for the H, counterclockwise and inward for the L. One point for the right letter and one for the right spin.

Scripture. "The wind goeth toward the south, and turneth about unto the north; it whirleth about continually, and the wind returneth again according to his circuits." (Ecclesiastes 1:6, KJV)

The Preacher noticed that the wind moves in great circuits. Weather maps show those circuits curling around highs and lows. The winds are not random; they follow the orderly ways God built into His world.

Practice answers

1. H stands for a high-pressure area, and L stands for a low-pressure area. They do not mean hot and low temperature.
2. A line on a weather map that connects places with the same air pressure.
3. Rising. Rising air cools and its water vapor condenses into clouds, so lows usually bring clouds, rain, snow or storms.
4. Clockwise and outward around a high; counterclockwise and inward around a low.
5. (a) Detroit, with the lowest pressure, 1001 mb. (b) Denver, with the highest, 1026 mb. (c) 1026 − 1001 = 25 millibars.
6. Over Texas. Close isobars mean the pressure changes a lot over a short distance, so the air rushes faster from high to low.

7. (a) The air pressure (and whether it rose or fell) and whether it rained, plus the sky. (b) Any two of: the time of day she reads it, the same barometer or same weather report source, the same place. (c) Weather changes for many reasons, so one or two days could be a coincidence; many days show whether there is a real pattern.
8. With your back to the wind, the low is on your left. Facing north, your left is west, so the low pressure is to the west (and the high is to the east).

Unit 2 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) Describe Torricelli's experiment of 1643. What did it show about air?
2. (5 pts) Why did Torricelli use mercury instead of water? About how tall would a water barometer need to be?
3. (5 pts) A mercury barometer reads 76 cm in the morning and 74 cm that evening. How much did it change? Did the air pressure rise or fall?
4. (5 pts) Explain how a jar-and-balloon barometer shows that air pressure is rising.
5. (5 pts) The weather report says 1018 millibars on Tuesday and 1006 millibars on Thursday. How much did the pressure change in all, and how much per day? What weather might be coming?
6. (5 pts) Experiment design: Ben keeps his jar barometer next to a heater that turns on and off. Why is this a problem, and how should he fix it?
7. (5 pts) Why does warm air rise? Use the words expand and dense.
8. (5 pts) Draw or describe the convection loop that makes a sea breeze on a sunny day.
9. (5 pts) Compare a high and a low: is air rising or sinking in each, what weather does each usually bring, and which way do winds curl around each in the Northern Hemisphere?
10. (5 pts) Town P reads 1028 millibars and Town Q reads 1008 millibars. Isobars are drawn every 4 millibars. How many isobars lie between the towns? Which town is more likely to be cloudy? If the isobars near Town Q are packed close together, what does that tell you?

Unit project: my air pressure weather station

Put together a display about the air over your home. Include your jar barometer (or a labeled photo or drawing of it), your seven-day log comparing the jar pointer with the official pressure, and a bar graph of the official readings. Add a labeled drawing of Torricelli's barometer, a sea-breeze convection diagram, and your hand-drawn weather map with isobars, an H, an L and wind arrows. Finish with a paragraph explaining what you learned about how air pressure and moving air shape the weather, and one sentence about which day your barometer warned you of a change.

- **Accuracy**: Drawings and labels are correct: the mercury column, the convection loop, the H and L, isobar numbers and the direction of the winds.
- **Records**: The barometer log has seven dated entries taken at the same time each day, and the bar graph matches the log.
- **Explanation**: The paragraph correctly explains air pressure, rising and falling pressure, why warm air rises, and what highs and lows bring, and names temperature as a variable to control.
- **Care**: The display is neat, clearly titled and easy for a visitor to follow.

Answer key

1. He filled a glass tube about 1 m long with mercury, turned it upside down in a dish of mercury, and the mercury dropped until it stood about 76 cm (30 in) high, leaving a vacuum at the top. It showed that air has weight: the air pressing on the dish holds up the mercury column.
2. Mercury is about 13.6 times heavier than water, so air holds up only about 76 cm of it. A water barometer would need a tube more than about 10 m (34 ft) tall.
3. 76 − 74 = 2 cm. The pressure fell, which often means clouds, rain or a storm may be coming.
4. When outside air pressure rises, it pushes harder on the balloon skin than the air sealed in the jar, so the skin dips in. The straw rests on the rim like a seesaw, so the pointer end tips up on the scale.
5. 1018 − 1006 = 12 millibars fall in 2 days, which is 6 millibars per day. Falling pressure often brings clouds, rain or storms.
6. Warming and cooling the air in the jar makes the skin puff up and sink, so the pointer moves even when the air pressure does not change. He should move the jar to a spot with steady temperature, away from heaters and sun, and read it at the same time each day so temperature is controlled.
7. When air is warmed it expands, so it takes up more space and becomes less dense than the cool air around it. The cooler, denser air sinks underneath and pushes the warm air up.
8. The sun heats the land faster than the sea. Warm air over the land rises; up high it flows out over the sea; over the cooler sea it sinks; near the ground cool air flows from the sea onto the land as a sea breeze.
9. High: air sinks, usually fair, clear weather; winds curl clockwise and outward. Low: air rises, usually clouds, rain or storms; winds curl counterclockwise and inward.
10. The isobars between them are 1012, 1016, 1020 and 1024: 4 isobars. Town Q (lower pressure) is more likely to be cloudy. Close isobars mean strong winds near Town Q.

UNIT 3

Clouds

Every day, without a sound, tons of water float over our heads. Clouds are made of billions of tiny droplets and ice crystals, and they come in shapes that can be named, sorted and read. In this unit you will learn how a London maker of medicines named Luke Howard gave the clouds their Latin names in 1802, and how later scientists settled on the ten cloud types that weather watchers use all over the world today.

You will stand with Elijah's servant on Mount Carmel watching a little cloud rise out of the sea, learn the sequence of clouds that often comes before a long rain, and run your own week-long forecast test. You will follow Dr. William Charles Wells into his garden at night as he weighs tufts of wool to discover where dew comes from, and you will find out why fog lies in valleys at sunrise. Last, you will climb Hampstead Heath with the painter John Constable and keep a two-week cloud photo journal of your own, the way real scientists keep records.

As you learn, remember the question God asked Job: "Dost thou know the balancings of the clouds?" (Job 37:16). The clouds are free and ever-changing, yet they follow faithful laws, and learning to read them is learning to read a page of God's handiwork.

BEFORE YOU BEGIN

- Knows that water can be a solid, a liquid or a gas (water vapor), and that water vapor condenses on a cold surface (Unit 1)
- Knows that warm air rises and that air pressure can rise and fall (Unit 2)
- Can read a thermometer in °C and °F and measure with a metric ruler
- Can read a simple table and bar graph and write simple fractions

MASTERY CHECKLIST

- I can tell how Luke Howard named the clouds and explain what cirrus, cumulus, stratus and nimbus mean.
- I can sort the ten cloud types into high, middle and low clouds and decode a cloud name from its word parts.
- I can read the sky for fair weather, coming rain and thunderstorms, and put in order the clouds that often come before a long rain.
- I can explain how dew, frost and fog form when air or a surface cools to the dew point, and tell what Wells learned with his wool.
- I can keep a cloud journal with date, time, direction, cloud type and cloud cover in oktas, and make a bar graph from my tally.
- I can plan a fair test by naming what I change, what I keep the same and what I measure.

OPTIONAL BOOKS AND RESOURCES

- **NASA GLOBE Observer (free app)** (https://observer.globe.gov/): Free. Families photograph the sky and report cloud types and cover, and NASA compares the reports with satellite views. A parent should set up the account. Use it with your Lesson 3.4 journal.
- **International Cloud Atlas, from the World Meteorological Organization** (https://cloudatlas.wmo.int/): Free online. The official world reference for the ten cloud types, with many photographs. Best browsed with a parent, since it is written for adults; the photos alone are a wonderful help for identifying clouds.
- **NOAA SciJinks** (https://scijinks.gov/): Free. Short articles, pictures and games from NOAA and NASA about clouds, fog, dew and weather, written for students.

3.1 Howard's Cloud Names and the Ten Cloud Types ★

OBJECTIVES

- Tell how Luke Howard named the clouds in 1802 and explain what cirrus, cumulus, stratus and nimbus mean.
- Explain that a cloud is made of tiny water droplets or ice crystals that form when rising air cools.
- Sort the ten cloud types into high, middle and low clouds and decode a cloud name from its word parts.

Warm-up. Look out a window or step outside (never look at the sun). Draw three clouds or cloud patterns you can see, or remember from another day. Give each one a name of your own invention, such as "cotton heap" or "feather streak." Now compare with someone else in your family: did you choose the same names? That is the very problem Luke Howard solved.

Video. Coming soon. Ten cloud types for kids (cirrus, cumulus, stratus, nimbus; high, middle and low clouds) and Luke Howard naming the clouds: search NOAA SciJinks, NASA GLOBE Observer, Met Office cloud-spotting guides, SciShow Kids, Homeschool Pop (Alternate) and time-lapse sky footage.

KEY TERMS

cloud
A huge crowd of tiny water droplets or ice crystals floating in the air.

water vapor
Water in the form of an invisible gas mixed into the air.

cirrus
Latin for "a curl of hair." Thin, wispy, high clouds made of ice crystals.

cumulus
Latin for "a heap." Puffy, piled-up clouds with flat bottoms.

stratus
Latin for "spread out." Flat, gray layers or sheets of cloud.

nimbus
Latin for "a rain cloud." In cloud names, nimbo- or -nimbus means the cloud brings rain or snow.

CORE IDEAS

The story. On an evening in December 1802, a young man named Luke Howard stood up to speak to a small science club in London called the Askesian Society. Howard was about thirty years old. He made and sold medicines for a living, and he was a Quaker who loved to study

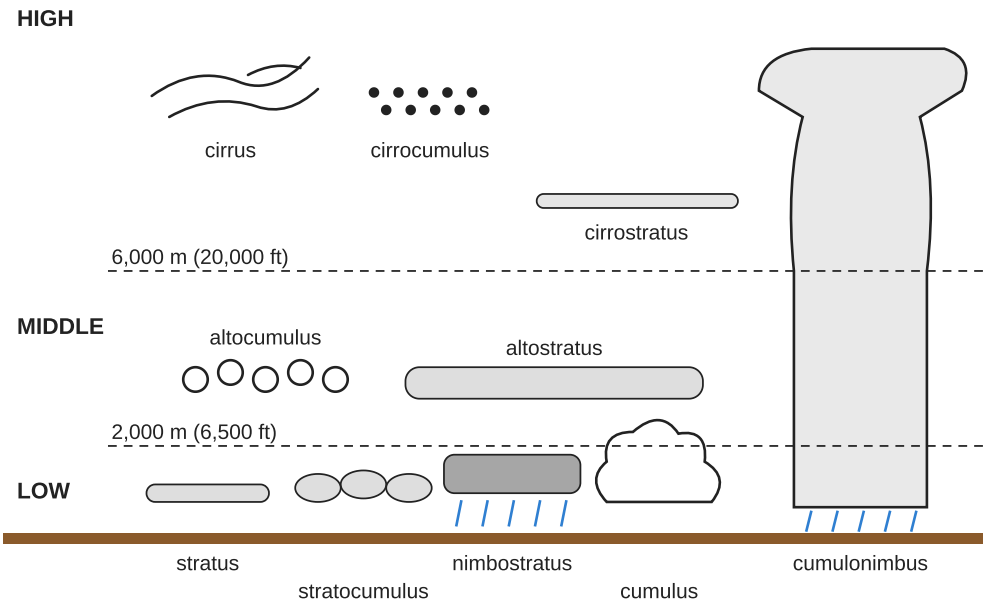
the works of God. Ever since he was a boy, he had watched the sky. His talk was called “On the Modifications of Clouds.” People had always looked at clouds, but no one had names for them that everyone agreed on. Clouds seemed too soft and too changeable to sort. Howard showed his listeners that clouds come in a few families that anyone, anywhere, can learn to recognize.

How they figured it out. Howard copied the plan of the great naturalist Carl Linnaeus, who gave plants and animals Latin names. Latin was the language that scientists in every country could read, so a cloud watcher in France, Germany or America could use the same words. Howard chose three main names: **cirrus** (a curl of hair) for thin, wispy streaks high in the sky; **cumulus** (a heap) for puffy, piled-up clouds; and **stratus** (spread out) for flat layers. He joined them to name in-between clouds, such as cirro-cumulus, and he used **nimbus** (a rain cloud) for the cloud that brings rain. His names caught on fast. The German poet Goethe admired them so much that he wrote poems in Howard’s honor. Later scientists built on his work. In 1887 the British meteorologist Ralph Abercromby and Hugo Hildebrandsson of Sweden proposed a list of ten cloud types, and Abercromby traveled around the world to check that clouds look the same in every land. They do. In 1896 the first *International Cloud Atlas* printed the ten types with photographs, and weather watchers still use those ten today.

The big idea. A cloud is made of billions of tiny water droplets or ice crystals. Clouds form when air rises and cools until some of its invisible **water vapor** condenses onto specks of dust, sea salt or smoke. Each droplet is so small that about a million of them would have to join together to make one raindrop. The ten cloud types are sorted by shape and by height (see the diagram). **High clouds**, with bases above about 6,000 meters (20,000 feet), are cirrus, cirrocumulus and cirrostratus. Up there it is so cold that they are made of ice crystals. **Middle clouds**, from about 2,000 to 6,000 meters (6,500 to 20,000 feet), are altocumulus and altostratus. **Low clouds**, below about 2,000 meters (6,500 feet), are stratus, stratocumulus and nimbostratus, the thick gray layer that brings steady rain. Two types start low and grow upward through the other levels: cumulus and cumulonimbus, the towering thunderstorm cloud.

Try it and see. Learn five word parts and you can decode every cloud name. *Cirro-* means high and icy. *Alto-* means a middle cloud (even though *alto* means “high” in Latin, a funny leftover from history). *Cumulo-* means heaped or lumpy. *Strato-* means a layer. *Nimbo-* means rain. So *nimbostratus* is a rain layer, *cumulonimbus* is a heaped rain cloud and *stratocumulus* is a layer of lumps. Cloud spotters also use a hand trick for lumpy clouds. Hold your arm straight out toward the clouds. If each lump looks about the size of your fist, it is probably stratocumulus. About the size of your thumbnail: altocumulus. Smaller than your little fingernail, like grains of rice: cirrocumulus.

God’s handiwork. Clouds look like the freest things in creation, drifting wherever the wind sends them. Yet Howard found that they follow order: the same shapes form again and again at the same heights, in England and in China, because they obey the laws God set in the air and the water. Long before Howard, the Lord asked Job, “Dost thou know the balancings of the clouds?” (Job 37:16). Every cloud you name is a small piece of that wonder.



The ten cloud types sorted by height. Dashed lines mark about 2,000 m (6,500 ft) and 6,000 m (20,000 ft).

PICTURE STUDY



The Windmill at Wijk bij Duurstede, Jacob van Ruisdael, about 1668–1670 · Oil on canvas · Rijksmuseum, Amsterdam

Jacob van Ruisdael was a Dutch painter who lived in Haarlem and Amsterdam. The Netherlands is a flat country, so the sky fills most of what a person sees, and Dutch painters became famous for their clouds. Ruisdael set the horizon very low in this picture and gave most of the canvas to the sky.

He painted it more than a hundred years before Luke Howard named the clouds, so Ruisdael had no Latin words for what he saw. But he watched carefully, and his clouds look like real ones. You can name them yourself.

Look closely

- Find the biggest, puffiest clouds. Which of Howard's names would you give them?
- Look for darker, grayer clouds. Are they higher or lower than the white heaps?
- How much of the picture is sky and how much is land and water? Estimate it as a fraction.
- Find the sails on the windmill and on the boat. What do they tell you about the wind that day?

Talk about it

1. Why do you think a Dutch miller or sailor would watch the clouds every day?
2. If you could send Ruisdael a letter, which three cloud names would you teach him first, and why?
3. Does the sky in this painting look like fair weather or like rain coming? What clues do you see?

> **Safety first.** Never look directly at the sun, even through clouds or sunglasses. Stand so a building or tree blocks the sun while you watch the sky. In the project, an adult should run the hot tap water and handle the spray can, and the room should have fresh air.

EXPERIMENT: MAKE A CLOUD IN A JAR: DO CLOUDS NEED DUST?

Howard learned that clouds form when moist air cools. Scientists later learned that the water also needs tiny specks to cling to. In this experiment you will make a small cloud inside a jar and test whether a puff of "dust" helps it form.

You will need

- Two identical clear glass jars (about 1 liter or 1 quart each)
- Hot water from the tap (not boiling), about 250 mL (1 cup) for each jar
- Two small metal plates or jar lids that cover the jar mouths
- Ice cubes
- A can of aerosol hairspray or air freshener (adult use only)
- A flashlight and a sheet of black paper
- Measuring cup, timer, lab notebook and pencil

Steps

1. Write the question in your notebook: Does a cloud form faster and thicker when there are tiny specks in the air?
2. Write your prediction and your reason.

3. Name the parts of your test. What we change: whether the jar gets a short puff of spray (the specks). What we keep the same: the jars, the amount and temperature of the water, the amount of ice, and the timing. What we measure: how thick the cloud looks after 30 seconds, on a scale of 0 (none) to 3 (thick and white).
4. An adult pours the same amount of hot tap water into each jar and swirls it once.
5. Lay the metal plates on top with the same number of ice cubes on each. Wait 1 minute.
6. An adult lifts one plate, gives that jar a very short puff of spray, and quickly sets the plate back on. Leave the other jar alone. It is your control.
7. Hold the black paper behind the jars and shine the flashlight through. After 30 seconds, rate each jar from 0 to 3.
8. Lift each plate and watch the cloud swirl out. Record what you see.
9. Repeat the whole test two more times with fresh hot water and record a table: Trial, Jar with specks, Jar without specks.
10. Write a conclusion of two sentences: Did the specks help? How does this match what you learned about real clouds?

Tips

- The flashlight and black background make thin clouds much easier to see.
- Even the jar without spray may make a faint cloud, because ordinary air already holds some dust.
- Do each trial the same way every time. That is what makes it a fair test.

Check your work

- I named what I changed, what I kept the same and what I measured.
- I repeated my test at least three times and recorded every trial.
- I can explain why a cloud needs both cooling and tiny specks.

FIELD NOTEBOOK

1. Draw the cloud-levels diagram in your own notebook. Label the ten cloud types and the heights of the dashed lines in meters and feet.
2. Make a word-part key: write cirro-, alto-, cumulo-, strato- and nimbo- with their meanings and a tiny picture beside each.
3. Go outside once each day for three days. Sketch the sky and write the cloud name you think fits, with the date and time.

> **From history.** Howard was not the only person trying to name clouds in 1802. In France that same year, the naturalist Jean-Baptiste Lamarck published his own list of cloud names, written in French. Lamarck’s names never caught on, partly because they were in one country’s language. Howard’s Latin names could be used by scientists everywhere, and they are the names we still use.

WORKED EXAMPLES

Example 1. Three pilots radio in. Pilot A sees a gray layer of cloud with its base at 1,200 m. Pilot B sees thin white streaks at 9,000 m. Pilot C sees rows of small puffy patches at 4,000 m. Sort each cloud into high, middle or low, give the height in feet, and name a likely cloud type.

(Use the map or drawing "Use the dashed lines to sort each pilot's cloud." shown earlier in this lesson.)

1. Recall the levels: low clouds are below about 2,000 m; middle clouds are about 2,000 to 6,000 m; high clouds are above about 6,000 m.
2. Pilot A: 1,200 m is below 2,000 m, so it is low. In feet: 1,200 × 3.28 ≈ 3,900 ft. A gray layer that low is stratus (or stratocumulus if it is lumpy).
3. Pilot B: 9,000 m is above 6,000 m, so it is high. In feet: 9,000 × 3.28 ≈ 29,500 ft. Thin white streaks up high are cirrus.
4. Pilot C: 4,000 m is between 2,000 and 6,000 m, so it is middle. In feet: 4,000 × 3.28 ≈ 13,100 ft. Small puffy patches at middle height are altocumulus.

Answer: A: low, about 3,900 ft, stratus. B: high, about 29,500 ft, cirrus. C: middle, about 13,100 ft, altocumulus.

Example 2. Decode the names *cirrostratus* and *cumulonimbus*. For each, tell its level and what it looks like.

1. Split each name into word parts: cirro + stratus, and cumulo + nimbus.
2. Cirro- means high and icy. Stratus means a layer. So cirrostratus is a high, icy layer: a thin, milky sheet across the sky.
3. Cumulo- means heaped. Nimbus means rain. So cumulonimbus is a heaped rain cloud: a giant puffy tower that brings rain, and often thunder and lightning.
4. Check the levels: cirrostratus begins with cirro-, so it is a high cloud. Cumulonimbus grows from low all the way up to the high level.

Answer: Cirrostratus: a high, thin, milky sheet of ice crystals. Cumulonimbus: a towering heaped rain cloud that grows from low to high and brings thunderstorms.

PRACTICE

1. EASY Who gave the clouds their Latin names, and in what year did he first present them?
2. EASY Match each name to its meaning: cirrus, cumulus, stratus, nimbus. Meanings: a heap, a rain cloud, a curl of hair, spread out.
3. EASY Name the three high cloud types. Why are they made of ice crystals instead of water droplets?

4. MEDIUM Decode *altostratus*. What level is it, and what does it look like?
5. MEDIUM Read the table and sort each cloud as high, middle, low or growing through several levels.
   Cloud A: base 500 m, top 900 m
   Cloud B: base 3,500 m, top 4,000 m
   Cloud C: base 7,500 m, top 8,000 m
   Cloud D: base 800 m, top 12,000 m
6. MEDIUM You hold your arm straight out. The cloud lumps in a wide layer each look about as big as your fist. Then on another day you see tiny lumps smaller than your little fingernail, high and white like grains of rice. Name each cloud.
7. HARD Experiment design. Sam wants to test whether a cloud in a jar forms better with hot water or with cool water. Name (a) what Sam changes, (b) three things Sam must keep the same, (c) what Sam measures and (d) why Sam should repeat the test.
8. CHALLENGE Ralph Abercromby traveled around the world to check whether clouds look the same in every land. In two or three sentences, explain why that was an important test of the ten cloud types.

COMMON MISTAKES

- Thinking clouds are made of water vapor. Water vapor is an invisible gas. A cloud is made of liquid droplets or ice crystals that have condensed out of the vapor, which is why you can see it.
- Thinking *alto* clouds are the highest clouds. Alto- clouds are middle clouds; the highest clouds begin with cirro-.
- Thinking every gray cloud is a rain cloud. Stratus and altostratus are gray but often bring no rain at all. The rain clouds are the ones with nimbo- or -nimbus in their names.

> **Make it a game · Cloud Word Builder.** Write the word parts cirro, alto, cumulo, strato, nimbo, cumulus, stratus and nimbus on index cards. Players take turns drawing two cards and putting them together. If the pair makes one of the ten real cloud types, the player names its level and describes it for 2 points. If it is a made-up cloud, the player gets 1 point for explaining why it is not on the list. First to 10 points wins.

> **Scripture.** “Dost thou know the balancings of the clouds, the wondrous works of him which is perfect in knowledge?” (Job 37:16, KJV)

Clouds hold tons of water, yet they float. God asked Job this question to show him how much wisdom lies in the ordinary sky. Naming the clouds is one way we begin to answer, “Not yet, Lord, but we are learning.”

Practice answers

1. Luke Howard, an English maker of medicines and Quaker, in December 1802 to the Askesian Society in London.
2. Cirrus: a curl of hair. Cumulus: a heap. Stratus: spread out. Nimbus: a rain cloud.

3. Cirrus, cirrocumulus and cirrostratus. They are so high, above about 6,000 m (20,000 ft), that the air is far below freezing.
4. Alto- means a middle cloud and stratus means a layer, so altostratus is a middle-level gray or bluish sheet that often covers the whole sky. The sun may look dim, as if seen through frosted glass.
5. A: low (below 2,000 m). B: middle (between 2,000 and 6,000 m). C: high (above 6,000 m). D: grows through all levels, from 800 m to 12,000 m; it is a cumulonimbus.
6. Fist-sized lumps in a layer: stratocumulus. Tiny high grains: cirrocumulus.
7. (a) The temperature of the water (hot or cool). (b) The same jars, the same amount of water, the same amount of ice, the same puff of spray or none, and the same waiting time. (c) How thick the cloud looks after a set time, on a 0 to 3 scale. (d) Repeating shows whether the result is real and not just luck or one mistake.
8. If clouds looked different in different places, one list of names could not work for the whole world. By checking many lands and finding the same shapes at the same heights, Abercromby showed that the clouds follow the same natural laws everywhere, so scientists in every country could share one set of names and compare their records.

3.2 What Clouds Forecast ★

OBJECTIVES

- Read the sky for fair weather, coming rain and thunderstorms using cloud types and how they change.
- Put in order the cloud sequence that often comes before a long rain: cirrus, cirrostratus, altostratus, nimbostratus.
- Test a cloud forecast with a simple record of predictions and results, and explain why a cloud is a clue and not a promise.

Warm-up. Ask everyone in your family: “What do you look at to decide whether to take an umbrella?” Write down every answer. Then step outside (never look at the sun) and make your own guess for the next six hours: dry, showers or steady rain. Seal your guess in an envelope and open it at supper.

Video. Coming soon. Reading clouds to forecast weather for kids (fair-weather cumulus, cumulonimbus anvils, halos, clouds thickening before rain), plus storm-cloud time-lapses: search NOAA SciJinks, National Weather Service SKYWARN spotter basics, NASA, Met Office, SciShow Kids and Homeschool Pop (Alternate).

KEY TERMS

forecast
A careful prediction of the weather to come, based on clues and records.

fair-weather cumulus
Small, flat-bottomed, puffy clouds spread far apart that do not grow tall. They usually mean dry weather.

cumulonimbus
A towering thunderstorm cloud that can bring lightning, heavy rain, hail and strong gusts of wind.

anvil
The flat, spreading top of a tall cumulonimbus, shaped like a blacksmith’s anvil.

halo
A ring of light around the sun or moon, made when light bends through the ice crystals of a cirrostratus cloud.

CORE IDEAS

The story. In the days of King Ahab of Israel, no rain had fallen for three and a half years (James 5:17). On Mount Carmel, a ridge that runs down to the Mediterranean Sea, the prophet Elijah prayed and sent his servant up to look out toward the sea. The servant came back: “There is nothing.” Seven times Elijah sent him. The seventh time the servant said,

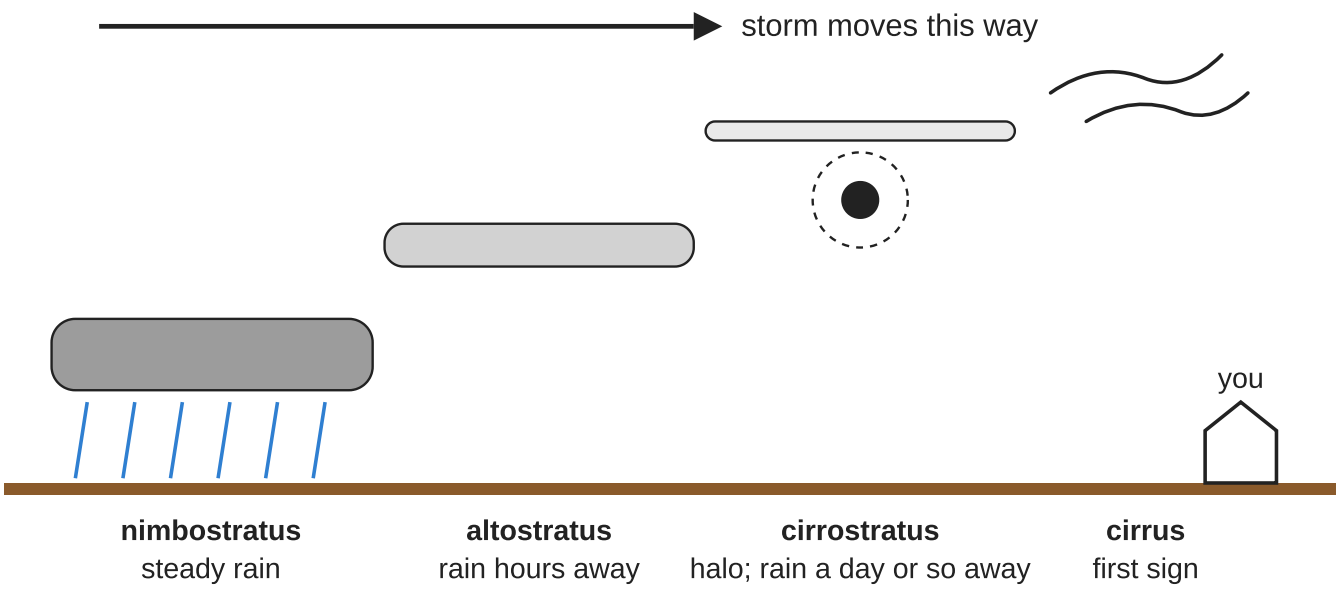
“Behold, there ariseth a little cloud out of the sea, like a man’s hand.” Elijah sent word at once to the king to get his chariot down the mountain before the rain stopped him. Soon “the heaven was black with clouds and wind, and there was a great rain” (1 Kings 18:43–45). The rain was God’s answer to prayer, and it came the way rain in that land usually comes: in clouds rolling in from the sea to the west. A watcher who knew the sky could read the first small cloud as a sign.

How they figured it out. Farmers and sailors have read clouds for thousands of years, and they passed on sayings. One old sailors’ rhyme says that a “mackerel sky” (rows of little cloud ripples, like the scales of a fish) and “mares’ tails” (long cirrus streaks) warn the ship to take in its sails. Around 1919, in Bergen, Norway, the scientist Vilhelm Bjerknes, his son Jacob and their team studied hundreds of weather reports and drew the pattern clearly. Before a large rainstorm arrives, the clouds often come in order. First come high cirrus streaks. They thicken into a milky cirrostratus sheet, often with a halo. Then the sheet lowers into gray altostratus, and the sun looks dim, as if seen through frosted glass. Last comes low, dark nimbostratus with steady rain or snow. You will learn more about the edges of these storms, called fronts, in Unit 5.

The big idea. Clouds show what the air is doing. Rising air cools and makes clouds; sinking air warms and dries them away. So the *change* in the clouds tells more than one look does. **Fair-weather cumulus**, small and flat-bottomed and far apart, usually mean a dry day, and they often shrink away by evening. Cumulus that keep growing taller by late morning warn of showers or storms by afternoon. A **cumulonimbus** with a flat **anvil** top means a thunderstorm is near: lightning, heavy rain, hail or strong gusts. High clouds that thicken, a **halo** around the sun or moon, and clouds that get lower and darker all say that rain or snow may come, often within a day or two. Flat gray stratus usually means a dull, damp day with perhaps a little drizzle.

In the world today. Weather forecasters now use satellites, radar and computers, but they still want human eyes on the sky. The National Weather Service trains volunteers called SKYWARN storm spotters to recognize storm clouds and report what they see. Pilots study clouds before every flight. A wise cloud reader knows that a cloud is a *clue*, not a promise. The best forecasts join several clues: the clouds, the wind, and a falling barometer like the one you built in Unit 2. Falling pressure together with thickening, lowering clouds is a much stronger sign of rain than either clue alone.

God’s handiwork. The Lord made the sky readable. The same cloud sequence that warned Norwegian fishermen warns farmers in Kansas, because God made the air and water follow faithful laws. Learning to read them lets us plan our work, keep safe and give thanks for the rain when it comes.



The cloud sequence that often comes before a long rain. The person at the house sees the clouds on the right first.

PICTURE STUDY



Seascape Study with Rain Cloud, John Constable, about 1824–1828 · Oil on paper · Royal Academy of Arts, London

John Constable grew up in Suffolk, England, where his father owned mills, and a miller's son learns early to watch the sky. In the 1820s Constable spent summers on the south coast of England and made many fast oil sketches on paper of the sea and the weather over it. This one, sometimes called *Rainstorm over the Sea*, was painted in minutes, before the storm moved on.

What Constable caught is a cumulonimbus cloud dropping a shower onto the sea. The dark streaks under the cloud are falling rain. A sailor who saw this cloud coming would know exactly what to expect in the next few minutes.

Look closely

- Find the rain. It is the gray curtain of streaks slanting from the bottom of the cloud down to the sea. Which way does it lean?
- Find the darkest part of the cloud and the brightest part of the sky. Where is the storm, and where is the fair weather?
- Find the small boats. Are they inside the rain or outside it?
- Look at the brushstrokes. Why do you think Constable painted this so quickly and roughly?

Talk about it

1. Which of Howard's cloud names fits the big cloud in this sketch? What tells you it is a rain cloud?
2. If you were in one of the boats and this cloud was moving toward you, what would you do, and how much time would you have?
3. Is this a long, steady rain or a short shower? What clues in the picture help you decide?

> **Safety first.** Never look directly at the sun. To see a halo, stand where a building, pole or tree blocks the sun itself. If you hear thunder or see a cumulonimbus with lightning close by, go indoors at once and stay in for 30 minutes after the last thunder.

EXPERIMENT: THE CLOUD FORECAST TEST

Can morning clouds tell you whether it will rain by evening? For one week you will be a weather spotter. Each morning you will read the sky, make a forecast and then check yourself. At the end you will know how good a forecaster the clouds made you.

You will need

- Lab notebook and pencil
- Your cloud word-part key from Lesson 3.1
- A rain gauge: a straight-sided clear jar with a ruler taped to the side, set in an open spot away from trees and roofs
- A clock or watch

Steps

1. Write the question: Can I forecast rain by evening from the clouds I see in the morning?
2. Choose one spot to stand and one direction to face (west is best, because much weather in the United States moves from west to east). Use the same spot and direction every day.

3. Rule a table with six columns: Date, Morning clouds (type and how much of the sky they cover), How the clouds are changing, My forecast (dry, showers or steady rain), Rain in gauge by evening (mm), Was I right?
4. Each morning at about the same time, look for 5 minutes. Name the cloud types, note whether they are growing, thickening or lowering, and write your forecast.
5. Check again at midday if you can. Write any changes, such as cumulus towering upward.
6. At the same time each evening, read the rain gauge in millimeters and write it down. Empty the gauge.
7. After 7 days, count how many forecasts were right. Write it as a fraction, such as 5 out of 7.
8. Write a short conclusion: Which clouds were the best clues? Which forecast fooled you, and why?

Tips

- Watch for change. Clouds that get thicker, lower or taller are stronger clues than any single look.
- If a day stays dry and clear, that counts too. Forecasting “dry” and being right is still a correct forecast.
- Keep this table. You will use it again in Lesson 3.4.

Check your work

- I made a forecast every morning before I knew the answer.
- I used the same spot, direction and times every day.
- I counted my correct forecasts and wrote them as a fraction.

FIELD NOTEBOOK

1. Draw the four-step cloud sequence before a long rain as a comic strip with four boxes. Label each cloud and how the sun looks behind it.
2. Draw a fair-weather cumulus and a cumulonimbus side by side. Label the flat base, the tall tower and the anvil.
3. Copy one weather saying your family knows. Beside it, write whether the clouds you studied today could explain it.

> **From history.** Beginning in the late 1960s and 1970s, the U.S. National Weather Service organized SKYWARN, a program that trains ordinary volunteers to spot dangerous storms. Spotters learn to tell a harmless low cloud from the parts of a cumulonimbus that can make hail or tornadoes, and they report what they see to forecasters. Even with radar and satellites, these trained human eyes have helped warn many towns in time.

WORKED EXAMPLES

Example 1. A girl keeps a sky log on a winter day. 7:00 a.m.: thin white streaks high in the west. 11:00 a.m.: a thin milky sheet over most of the sky, with a ring around the sun. 3:00 p.m.: a thicker gray sheet; the sun looks like a dim spot behind frosted glass. 6:00 p.m.: a low, dark gray layer moving in. What is her forecast for tonight, and why?

(Use the map or drawing "Match each entry in the log to a cloud in the diagram." shown earlier in this lesson.)

1. Name the clouds in order: 7:00 is cirrus, 11:00 is cirrostratus (the ring is a halo), 3:00 is altostratus, 6:00 is the start of nimbostratus.
2. Look at the change: the clouds have gone from high to middle to low, and from thin to thick.
3. That is the classic sequence that often comes before a long rain or snow.
4. Because the low dark layer is already arriving, the rain or snow is probably only hours away. In winter with cold air, it might be snow.

Answer: Steady rain or snow is likely tonight, because the clouds followed the cirrus, cirrostratus, altostratus, nimbostratus sequence, getting thicker and lower all day.

Example 2. Ben kept a record for 20 mornings. Use his table to answer: (a) Which morning clue was followed by rain most often? (b) When he saw only fair-weather cumulus, how often did the day stay dry?

Fair-weather cumulus only: 8 mornings, rain later on 1
Cumulus towering by 11 a.m.: 5 mornings, rain later on 4
Halo or thickening cirrostratus: 4 mornings, rain within a day on 3
Flat gray stratus: 3 mornings, drizzle on 1

1. Check the total: $8 + 5 + 4 + 3 = 20$ mornings.
2. Write each rain record as a fraction: towering cumulus 4 out of 5; halo 3 out of 4; stratus 1 out of 3; fair-weather cumulus 1 out of 8.
3. Compare the two biggest: 4 out of 5 is 80 out of 100 (80%), and 3 out of 4 is 75 out of 100 (75%). So towering cumulus was the best rain clue.
4. Fair-weather cumulus: rain on 1 of 8 mornings, so the day stayed dry on $8 - 1 = 7$ of 8 mornings.

Answer: (a) Cumulus towering by 11 a.m., followed by rain on 4 of 5 mornings (80%). (b) The day stayed dry on 7 of 8 fair-weather cumulus mornings.

PRACTICE

1. EASY What did Elijah’s servant see from Mount Carmel on the seventh look, and what happened next?
2. EASY Which cloud brings lightning, hail and heavy rain? What shape is its top often like?
3. EASY What makes a halo around the sun or moon, and what can it warn of?
4. MEDIUM Put these clouds in the order they often appear before a long rain: altostratus, cirrus, nimbostratus, cirrostratus.
5. MEDIUM A spotter measures the top of a growing cumulus cloud every hour.
   10 a.m.: 1,500 m
   11 a.m.: 3,500 m
   12 noon: 5,500 m
   1 p.m.: 7,500 m
   2 p.m.: 9,500 m
   (a) How many meters did the top grow each hour? (b) About how many feet is that? (c) What is your forecast for the afternoon?
6. MEDIUM At 4 p.m. on a summer day you see small, flat-bottomed cumulus, far apart, that seem to be shrinking. What is your forecast for the evening?
7. HARD Experiment design. Grandpa says, “A ring around the moon means rain within two days.” Plan a fair test. Tell (a) what you will look for each night, (b) what you will measure afterward, (c) what you must also record on nights with no ring, and (d) why one night is not enough.
8. CHALLENGE In two or three sentences, explain why a falling barometer together with thickening, lowering clouds is a stronger forecast than either clue alone.

COMMON MISTAKES

- Thinking any cumulus cloud means rain. Small fair-weather cumulus usually mean dry weather. Watch whether they grow tall.
- Thinking dark clouds are always the dangerous ones. A cumulonimbus can look brilliant white on top in the sunshine while it makes lightning and hail underneath.
- Treating a cloud forecast as a promise. Clouds are clues, and good forecasters check several clues and keep records of how often they are right.

Make it a game · Sky Detective. A parent describes a sky in one or two sentences, such as “Tall puffy clouds growing fast at noon” or “A ring around the moon tonight.” The player names the cloud type and gives a forecast. Score 1 point for the cloud name and 1 point for a sensible forecast with a reason. Then switch: the player describes a sky and the parent forecasts. First to 10 points wins.

Scripture. “And it came to pass at the seventh time, that he said, Behold, there ariseth a little cloud out of the sea, like a man's hand. And he said, Go up, say unto Ahab, Prepare thy chariot, and get thee down, that the rain stop thee not.” (1 Kings 18:44, KJV)

Elijah trusted God to send rain, and he also read the sky. When the servant saw a small cloud rising from the sea, Elijah knew the storm was on its way and acted at once. Faith and careful watching go together.

Practice answers

1. A little cloud rising out of the sea, like a man’s hand. Soon the sky grew black with clouds and wind, and a great rain fell (1 Kings 18:44–45).
2. Cumulonimbus. Its top often spreads out flat like an anvil.
3. Light bending through the ice crystals of a thin cirrostratus cloud. It can warn that rain or snow may come, often within a day or two.
4. Cirrus, cirrostratus, altostratus, nimbostratus.
5. (a) 2,000 m each hour (for example, 3,500 − 1,500 = 2,000). (b) About 6,600 ft (2,000 × 3.28 = 6,560). (c) The cloud is growing into a cumulonimbus, so expect a thunderstorm with heavy rain and possibly lightning or hail by afternoon.
6. Fair, dry weather. Small fair-weather cumulus that shrink in late afternoon show that the air is not rising strongly enough to build storms.
7. (a) Whether there is a ring (halo) around the moon, at the same time each clear-moon night. (b) Whether the rain gauge collects rain in the next two days, in millimeters. (c) Whether it rained in the two days after no-ring nights too; those nights are the comparison (control), to show whether rain is more likely after a ring than without one. (d) One night could be luck; many nights show whether the saying usually holds.
8. Each clue alone can sometimes fool you: clouds may thicken and then break up, and pressure can dip a little without rain. When two different kinds of evidence point the same way, it is much more likely that a real storm system is coming, so the forecast is more trustworthy.

3.3 Fog and Dew

OBJECTIVES

- Explain that dew, frost and fog form when air or a surface cools to the dew point.
- Tell how William Charles Wells showed with tufts of wool that dew does not fall from the sky.
- Describe radiation fog and advection fog and predict whether dew or fog is likely from the temperature and dew point.

Warm-up. Early tomorrow morning, before the sun is high, go outside with a parent. Touch the grass, a car window and a metal railing. Which are wet? Which are dry? Write down your guess: did the water fall from the sky, rise out of the ground, or come out of the air?

Video. Coming soon. How dew, frost and fog form (dew point, radiation fog, advection fog, San Francisco fog time-lapse) for kids: search NOAA SciJinks, National Weather Service, NASA Earth Observatory, Met Office, SciShow Kids, Science Max and nature footage of morning fog.

KEY TERMS

dew
Drops of water that form on cool surfaces, such as grass, when water vapor in the air condenses.

dew point
The temperature to which air must cool for its water vapor to begin condensing into liquid water.

frost
Ice crystals that form on a surface when it cools to a dew point that is below freezing, 0°C (32°F).

fog
A cloud touching the ground. Weather observers call it fog when it cuts the distance you can see to less than 1 kilometer (about 0.6 mile).

radiation fog
Fog that forms on clear, calm nights when the ground loses heat to the sky and cools the air just above it.

advection fog
Fog that forms when moist air blows over a cold surface, such as a cold ocean current, and is cooled to its dew point.

CORE IDEAS

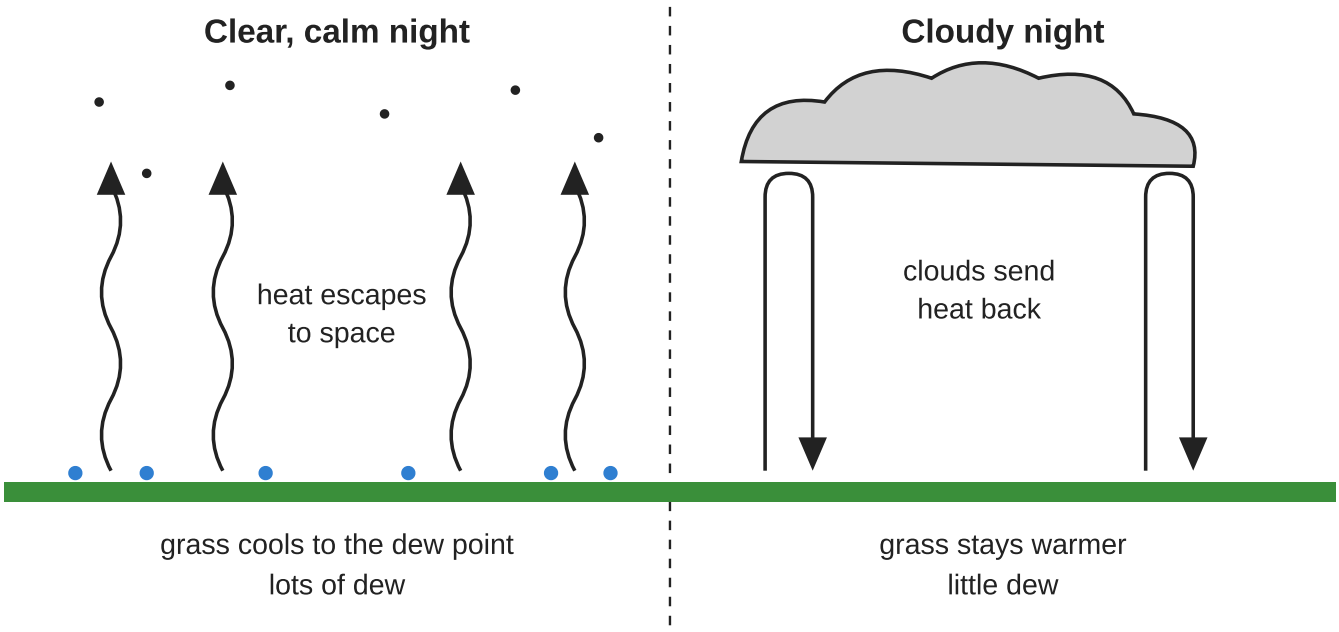
The story. William Charles Wells was born in Charleston, South Carolina, in 1757 and became a doctor in London. In his spare hours he wondered about something everyone had seen and few understood: dew. Some people said dew fell from the sky like a very fine rain. Others said it rose out of the ground like steam. Wells decided to find out. Night after night, in a garden near London, he set out small tufts of wool that he had carefully weighed. In the morning he weighed them again. In 1814 he published what he learned in a little book called *An Essay on Dew*.

How they figured it out. Wells set some tufts on open grass and some under a cover, like a board held up above the grass. The wool under the open sky gained much more weight from dew than the covered wool. Clear, calm nights gave the most dew. Cloudy nights and windy nights gave little. With thermometers he found that on clear nights the grass became several degrees colder than the air a little higher up. Wells concluded that dew does not fall at all. The grass and the wool give off heat to the clear night sky, they grow cold, and the moist air touching them is chilled until its water condenses on them. Clouds or a board act like a blanket, sending heat back down, so the surface stays warmer and little dew forms (see the diagram).

The big idea. Air always holds some invisible water vapor. Cool the air enough, and the vapor begins to condense into liquid water. The temperature where this happens is called the **dew point**. When a surface such as a leaf cools to the dew point, **dew** forms on it. If the dew point is below freezing, 0°C (32°F), the vapor turns straight into ice crystals on the surface, and we call it **frost**. When a whole layer of air near the ground cools to its dew point, tiny droplets form all through the air instead of only on surfaces. That is **fog**, which is simply a cloud touching the ground. The closer the air temperature is to the dew point, the more likely dew and fog become.

Two kinds of fog. Radiation fog forms on clear, calm nights, just as Wells's dew did. The ground cools, it cools the air above it, and because cold air is heavy it slides down and collects in valleys and low fields. That is why you often see fog lying in low places at sunrise. When the sun warms the ground and the air, the droplets evaporate and the fog "burns off." **Advection fog** forms when moist air blows over something cold. In summer, damp air from the Pacific Ocean flows over cold water near San Francisco and turns into thick fog that pours through the Golden Gate. Off Newfoundland, on the Grand Banks, warm moist air meets cold ocean water, and fog is so common that ships have long sounded foghorns there.

God's handiwork. Dew is a quiet gift. In dry lands it waters plants every clear night without a single raindrop. In the Namib Desert of Africa some beetles stand on dune tops in the morning fog and let droplets gather on their backs and roll down to their mouths. In parts of Chile, people stretch fine nets to catch fog and collect drinking water. Long before Wells, Gideon laid out a fleece of wool and in the morning wrung from it "a bowl full of water" (Judges 6:38). Wool was catching dew in Gideon's day, and Wells used the same humble material to uncover how God waters the earth.



Why Wells found the most dew on clear, calm nights: with no clouds, heat escapes and the grass cools to the dew point.

PICTURE STUDY



Morning Mist in the Mountains, Caspar David Friedrich, 1808 · Oil on canvas · Thüringer Landesmuseum Heidecksburg, Rudolstadt, Germany

Caspar David Friedrich was a German painter who loved mountains, mist and the quiet of early morning. He walked for days in the hills of Germany and Bohemia with a sketchbook, and later turned his drawings into paintings like this one. Here the sun has just come up, and a mountain peak stands above a sea of fog that fills every valley below.

The fog in this picture is a cloud lying on the ground, the very thing you are studying in this lesson. On a clear, calm night the ground cools, the air above it cools to its dew point, and the cold, heavy air slides down into the low places. By sunrise the valleys are full of white, and only the high ground pokes through.

Look closely

- Find where the fog is thickest. Is it low in the valleys or high on the peak?
- Find the trees that stick up out of the mist. What does that tell you about how deep the fog is?
- Look at the sky above the mountain. Is it clear or cloudy? How could a clear night have helped make this fog?
- Look at the very top of the peak. What do you see there?

Talk about it

1. If you waited on the peak until midday, what do you think would happen to the fog? Why?
2. Which kind of fog do you think this is, radiation fog or advection fog? Give your reason.
3. How would the world look to someone standing down in the valley at the same moment?

> **Safety first.** Go outside at night or before sunrise only with an adult, and stay off roads, especially in fog, when drivers cannot see far. If you use warm water for the fog-in-a-jar extra, use tap water, not boiling water.

EXPERIMENT: WELLS'S DEW TEST

You will repeat William Charles Wells's famous test with two cloths and a kitchen scale. The question: Does more dew form on cloth under the open sky than on cloth under a cover?

You will need

- Two identical small cotton washcloths or squares cut from an old towel (about 20 cm by 20 cm, or 8 in by 8 in)
- A kitchen scale that reads in grams
- Two zip-top plastic bags
- A board, tray or flattened cardboard box, and four bricks, cans or books to hold it about 30 cm (1 ft) above the grass
- An outdoor thermometer (optional)
- Lab notebook and pencil

Steps

1. Write your question and your prediction. Which cloth will gain more weight, and why?

2. Name the parts of the test. What we change: whether the cloth is under open sky or under a cover. What we keep the same: the kind and size of cloth, the grass it sits on, the night, and the times we set out and collect. What we measure: how many grams of water each cloth gains.
3. In the evening, weigh each dry cloth inside its own zip bag and write the weights.
4. Lay one cloth flat on open grass, away from trees and buildings. Lay the other on grass nearby and set up the board above it on the bricks. This covered cloth is your control.
5. Write the weather: clear or cloudy, calm or windy. If you have a thermometer, read the air temperature.
6. At sunrise, put each cloth straight into its own bag and seal it so the dew cannot dry. Weigh each bag again.
7. Subtract to find the gain: morning weight minus evening weight.
8. Repeat on at least two more nights, including one cloudy or windy night if you can. Record everything in a table: Night, Sky, Wind, Open cloth gain (g), Covered cloth gain (g).
9. Write a conclusion: On which kind of night did the most dew form? Did the cover make a difference? Compare your results with Wells's.

Tips

- Weighing each cloth inside its own sealed bag keeps the dew from drying while you carry it in. Weigh the same bag with the same cloth each time.
- If the gain is only 1 or 2 grams, that still counts. Small numbers are real data.
- Extra: Fill a clear jar one-third full with warm tap water, set a metal lid with ice on top and look for a faint fog forming inside. Shine a flashlight through it against black paper.

Check your work

- I named what I changed, what I kept the same and what I measured.
- I tested on more than one night and recorded the sky and wind each time.
- I can explain, as Wells did, why open grass gets more dew on a clear night.

FIELD NOTEBOOK

1. Draw the two-night diagram from this lesson: a clear night and a cloudy night. Use arrows to show where the heat goes.
2. Early one morning, draw a blade of grass or a spider web with dew on it. Count the drops you can see on one blade and write the number, the date and the time.
3. Draw a valley with fog lying in it at sunrise. Label the cold air sinking into the low ground.

> **From history.** Wells's *Essay on Dew* became famous as a model of how to do science: a simple question, careful weighing, many nights of patient records, and a comparison between covered and uncovered wool. Writers about science praised it for many years

afterward as an example of a clear, fair experiment. All he needed was a garden, a scale, some thermometers and wool.

WORKED EXAMPLES

Example 1. Like Wells, Clara tested two cloths on a clear, calm night. The open cloth weighed 50 g in the evening and 58 g in the morning. The covered cloth weighed 50 g in the evening and 51 g in the morning. How much dew did each gain, and how many times as much did the open cloth gain?

1. Open cloth: 58 g − 50 g = 8 g of dew.
2. Covered cloth: 51 g − 50 g = 1 g of dew.
3. Compare: 8 g ÷ 1 g = 8.
4. Explain: the open cloth lost heat to the clear sky and cooled to the dew point; the board sent heat back down to the covered cloth, so it stayed warmer.

Answer: The open cloth gained 8 g and the covered cloth gained 1 g, so the open cloth gained 8 times as much dew.

Example 2. At 9:00 p.m. the air temperature is 14°C (57°F) and the dew point is 10°C (50°F). The night is clear and calm, and the air is cooling about 1°C each hour. About what time will the air reach the dew point, and what might you see in the morning?

(Use the map or drawing "A clear, calm night lets the ground and air cool to the dew point." shown earlier in this lesson.)

1. Find the gap between temperature and dew point: 14°C − 10°C = 4°C.
2. The air cools 1°C each hour, so it needs 4 ÷ 1 = 4 hours.
3. Count forward 4 hours from 9:00 p.m.: 10, 11, 12, 1:00 a.m.
4. After that the grass and air keep cooling, so water vapor condenses. The dew point, 10°C, is above freezing, so it will be dew, not frost.

Answer: About 1:00 a.m. Expect heavy dew on the grass by morning, and possibly fog in low places, because the night is clear and calm.

PRACTICE

1. EASY What is fog?
2. EASY Wells found the most dew on which kind of night: clear and calm, cloudy, or windy?
3. EASY What is the difference between dew and frost?
4. MEDIUM Which evening is more likely to bring fog by morning, and why?
   Evening A: temperature 20°C (68°F), dew point 19°C (66°F), clear and calm.
   Evening B: temperature 25°C (77°F), dew point 10°C (50°F), clear and calm.

5. MEDIUM Read the table of a student's dew test (open cloth only).
   Night 1: clear, calm, gain 9 g
   Night 2: cloudy, calm, gain 2 g
   Night 3: clear, windy, gain 3 g
   Night 4: clear, calm, gain 11 g
   (a) What was the average gain on clear, calm nights? (b) Which two things together made the most dew?
6. MEDIUM Why does fog often lie in valleys and low fields at sunrise, while the hilltops stay clear?
7. HARD Experiment design. You want to find out whether more dew forms on grass or on a concrete driveway. Tell (a) what you change, (b) three things you keep the same and (c) what you measure.
8. CHALLENGE People say morning fog "burns off." Nothing is really burning. In two or three sentences, explain what actually happens.

COMMON MISTAKES

- Thinking dew falls from the sky like a fine rain. Wells showed that it forms right where you find it, when a cool surface chills the moist air touching it.
- Thinking fog is smoke or something different from a cloud. Fog is made of the same tiny water droplets as a cloud; it is a cloud at ground level.
- Thinking frost is always frozen dew. Most frost forms when water vapor turns straight into ice on a surface that is below freezing, without becoming liquid first.

Make it a game · Dew, Frost or Fog?. A parent reads a weather situation, such as "Clear, calm night, dew point 5°C" or "Clear, calm night, dew point −3°C" or "Damp sea air blowing over cold water." The player calls out dew, frost or fog and gives the reason. One point for the right answer and one for the reason. After eight rounds, the player makes up three situations for the parent.

Scripture. "And it was so: for he rose up early on the morrow, and thrust the fleece together, and wringed the dew out of the fleece, a bowl full of water." (Judges 6:38, KJV)

Gideon asked God for a sign, and God answered through the dew on a fleece of wool. The sign was a miracle, and it also shows that dew was a familiar, precious thing in Israel, where rain does not fall for months in summer. Wells used wool to learn how God sends ordinary dew each clear night.

Practice answers

1. A cloud touching the ground: tiny water droplets filling the air near the surface, thick enough that you cannot see as far as 1 km (about 0.6 mile).
2. Clear and calm.
3. Dew is liquid water drops that form when the dew point is above freezing. Frost is ice crystals that form when the dew point is below freezing, 0°C (32°F).

4. Evening A. The temperature is only 1°C above the dew point, so a little cooling will make the vapor condense. In Evening B the air must cool 15°C before reaching the dew point.
5. (a) (9 + 11) ÷ 2 = 10 g. (b) A clear sky and calm air. Clouds (Night 2) and wind (Night 3) both cut the dew a great deal.
6. On clear, calm nights the ground cools the air above it. Cold air is heavier, so it slides downhill and collects in low places, where it cools to the dew point and forms radiation fog.
7. (a) The surface under the cloth: grass or concrete. (b) The same kind and size of cloth, the same night, the same times to set out and collect, both under open sky, and the same scale. (c) The grams of water each cloth gains overnight. (Repeat on several nights.)
8. The morning sun warms the ground, and the ground warms the air above it. As the air warms above its dew point, the tiny fog droplets evaporate back into invisible water vapor, so the fog thins and disappears.

3.4 Cloud Photo Journal

OBJECTIVES

- Keep a cloud journal with a photo or sketch, date, time, direction, cloud type, cloud cover and weather for each observation.
- Measure cloud cover in eighths of the sky (oktas) and name it clear, few, scattered, broken or overcast.
- Tally journal records, draw a bar graph and use it to find patterns and check cloud forecasts.

Warm-up. Take or find any photo of the sky on a family phone or in an album. Without looking at the date stamp, can you tell what day it was taken, what time, or which way the camera faced? Make a list of everything you would need to write beside a sky photo so that a scientist a hundred years from now could use it.

Video. Coming soon. How to photograph and log clouds for citizen science (NASA GLOBE Observer clouds, estimating cloud cover, cloud time-lapse) and John Constable's cloud studies: search NASA GLOBE Program, NOAA SciJinks, Met Office, Royal Academy or Tate art videos about Constable, and Homeschool Pop (Alternate).

KEY TERMS

observation
Something you notice carefully with your senses or with an instrument and write down.

data
Facts and measurements that are recorded so they can be compared and studied.

cloud cover
How much of the sky is hidden by clouds.

okta
One eighth of the sky. Weather observers measure cloud cover from 0 oktas (clear) to 8 oktas (completely covered).

tally
A quick count made with marks, usually grouped in fives.

CORE IDEAS

The story. In the summers and autumns of 1821 and 1822, the English painter John Constable carried his paints up to Hampstead Heath, a high, open hill just north of London. There he painted the sky again and again, sometimes several times in one day. In a letter to his friend John Fisher, he called this work "skying." He made dozens of quick oil sketches of clouds on paper. On the backs of many of them he wrote notes: the date, the time of day, the direction he was facing and the wind. One note, for example, records a morning in

September at ten o’clock, looking southeast, with a brisk wind from the west and gray clouds running fast across the sky.

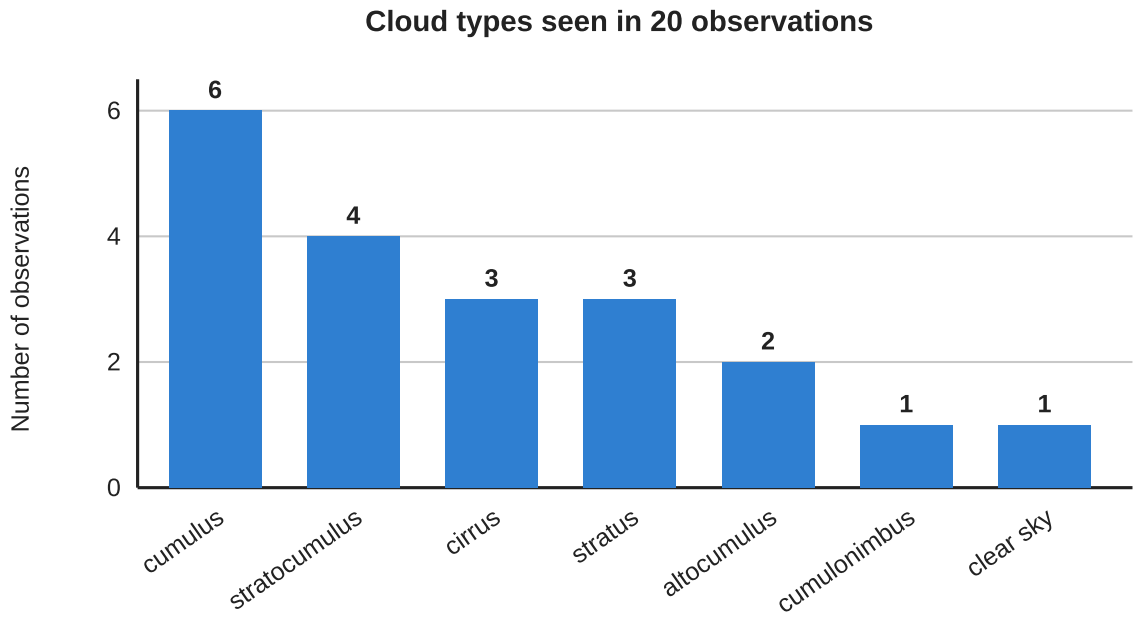
How they figured it out. Why did a painter write down the time and the wind? Because a cloud picture without them is only half a record. With the notes, Constable could remember exactly what kind of day had made those clouds. Scientists keep records the same way. Luke Howard, who named the clouds, kept daily weather records in London for years and used them to write a book about the climate of London. A good record always answers the same questions: *When? Where? Which way? What did I see? What happened next?* If you take a photo every day from the same spot, facing the same way, at the same times, then the only thing that changes is the sky itself. That makes the comparisons fair.

The big idea. A journal turns watching into **data**. Weather observers measure **cloud cover** in **oktas**, or eighths of the sky. Picture the sky cut into 8 equal slices like a pie. If clouds would fill 2 slices, the cover is 2 oktas. Pilots’ weather reports use these words: 0 oktas is *clear*, 1 to 2 oktas is *few*, 3 to 4 is *scattered*, 5 to 7 is *broken*, and 8 is *overcast*. After many days of records, you can **tally** the cloud types, draw a bar graph (see the figure) and look for patterns. Which cloud do you see most? Which clouds came before rain? Was the sky cloudier in the afternoon than in the morning? One day proves nothing, but twenty days begin to tell a story.

Try it and see. To take a good cloud photo, include a little bit of ground, such as a rooftop or treetop, so the picture shows size and direction. Never point the camera at the sun, and never look at the sun through a camera or phone. Hold the camera level and take one wide picture of the whole sky in that direction, then one closer picture of the most interesting cloud. If you do not have a camera, do what Constable did: make a quick sketch in two minutes with pencil or colored pencils, and shade the gray parts. Then write your notes right away, while the sky is still in front of you.

In the world today. NASA runs a free program called GLOBE Observer, in which families and students photograph the sky and report the cloud types and cloud cover they see. Scientists compare these ground photos with pictures taken at the same time by satellites looking down from space. A satellite sees the tops of the clouds, and you see the bottoms, so your observations help them understand the whole cloud. Your journal can be real science, the same kind that Howard and Constable did with notebook and brush.

God’s handiwork. No two skies are ever exactly alike, yet every cloud follows the same faithful laws. The psalmist praised the God “who covereth the heaven with clouds” (Psalm 147:8). A cloud journal is a way of paying attention, day after day, to that daily work of His hands.



A sample cloud journal tally made into a bar graph. Each bar shows how many of the 20 observations had that main cloud type.

PICTURE STUDY



Cloud Study, John Constable, 1821 · Oil on paper · Yale Center for British Art, New Haven, Connecticut

In 1821 and 1822, John Constable painted dozens of small studies of the sky from Hampstead Heath, near London. Many of them show no buildings, no people and hardly any land. They are portraits of clouds. Constable believed that the sky set the mood of every landscape, so he trained his eye on it the way a scientist trains an eye on a specimen.

He painted these studies fast, often in less than an hour, because clouds change quickly. Then he turned the paper over and wrote down the date, the time and the wind. They are paintings and weather records at the same time.

Look closely

- Find the brightest part of the clouds. Where do you think the sun is?
- Find the gray undersides of the clouds. Are their bottoms flat or ragged?
- Which of Howard's cloud names fits these clouds best? Look for heaps, layers and wisps.
- Look at the brushstrokes. Do they look slow and careful, or quick? Why would Constable paint quickly?

Talk about it

1. If you could read the note on the back of this painting, what three things would you most want it to tell you?
2. How is Constable's cloud study like a photo in your cloud journal? How is it different?
3. What weather do you think came a few hours after this sky? What makes you think so?

> **Safety first.** Never look at the sun or point a camera or phone at it; viewing the sun through a camera or phone screen is not safe either. Stay on the ground and in your own yard or another safe spot chosen with a parent. Do not climb on roofs or ladders for a better view. Go indoors if you hear thunder.

EXPERIMENT: MY TWO-WEEK CLOUD PHOTO JOURNAL

For 10 to 14 days you will photograph or sketch the sky twice a day and keep a scientist's journal. At the end you will tally your cloud types, make a bar graph and check which clouds came before rain. This journal is the main part of your unit portfolio.

You will need

- A camera or phone (with a parent's permission), or a sketchbook and colored pencils
- Lab notebook or printed journal pages
- Your cloud word-part key from Lesson 3.1 and your forecast table from Lesson 3.2
- Your rain gauge from Lesson 3.2
- A compass, or a parent to help you find north, south, east and west
- Graph paper and a ruler

Steps

1. Write your two questions: Which cloud types appear most often over my home? Which clouds come before rain?
2. Choose one spot to stand and one direction to face. Mark the spot so you can find it every day. Choose two times, such as 8 a.m. and 4 p.m.

3. Make a journal page for each day with these headings: Date, Time, Facing, Photo or sketch number, Main cloud type, Other clouds, Cloud cover (oktas), Wind (calm, light or strong, and from which direction), Weather now, Rain in gauge by next morning (mm).
4. At each time, take one wide photo and one close photo, or make a two-minute sketch. Fill in every heading right away.
5. To find oktas, imagine the sky cut into 8 equal pie slices. Count how many slices the clouds would fill if you pushed them together.
6. Read the rain gauge each morning, write the amount and empty it.
7. After 10 to 14 days, make a tally of the main cloud type for every observation.
8. Draw a bar graph of your tally on graph paper. Label both axes and give it a title.
9. Look back: on the days before rain, which clouds did you record? Write two or three sentences about any pattern you found.
10. Choose your six best photos or sketches, each of a different cloud type if you can, and label them for your portfolio.

Tips

- Missing one observation is fine. Write “missed” instead of guessing afterward. Honest records are better than perfect-looking ones.
- If you cannot decide on the cloud type, write your best guess and a question mark. Scientists do that too.
- Clear-sky observations count. A clear sky is data.

Check your work

- I used the same spot, direction and times for every observation.
- Every photo or sketch has a date, time, direction, cloud type, cloud cover and weather written beside it.
- I made a labeled bar graph and wrote about one pattern I found.

FIELD NOTEBOOK

1. Paint or color one “skying” study in the style of Constable. On the back, write the date, time, direction you faced and the wind.
2. Draw a circle and divide it into 8 equal slices. Shade the number of slices that match today’s cloud cover and write the number of oktas and its name.
3. At the end of your journal, draw your favorite cloud from the whole two weeks and write why you chose it.

> **From history.** Luke Howard did more than name clouds. For many years he kept daily records of temperature, pressure, wind and rain near London and published them in a book called *The Climate of London*. Comparing his numbers with readings from the countryside, he noticed that the city was often warmer than the open country around it,

especially at night. Scientists still study this effect today, and it was discovered because one man kept a careful journal.

WORKED EXAMPLES

Example 1. Use the bar graph of 20 journal observations. (a) Which cloud type was seen most often? (b) How many more times was cumulus seen than stratus? (c) What fraction of the observations were cumulus, and what is that as a percent?

(Use the map or drawing "Read each bar against the numbers on the left side." shown earlier in this lesson.)

1. Read each bar: cumulus 6, stratocumulus 4, cirrus 3, stratus 3, altocumulus 2, cumulonimbus 1, clear sky 1.
2. Check the total: 6 + 4 + 3 + 3 + 2 + 1 + 1 = 20. Good, it matches.
3. (a) The tallest bar is cumulus, with 6.
4. (b) 6 − 3 = 3 more times.
5. (c) Cumulus was 6 out of 20, or 6/20. Divide top and bottom by 2: 3/10. Three tenths is 30 out of 100, or 30%.

Answer: (a) Cumulus. (b) 3 more times. (c) 6/20 = 3/10 = 30%.

Example 2. Luis imagines the sky as 8 equal slices. If he pushed all the clouds together, they would fill 6 slices. How many oktas is that? What word would a pilot's weather report use? What fraction and percent of the sky is covered?

1. Each slice is one okta, so 6 slices = 6 oktas.
2. Use the scale: 0 clear, 1 to 2 few, 3 to 4 scattered, 5 to 7 broken, 8 overcast. 6 is between 5 and 7, so it is broken.
3. Fraction: 6/8. Divide top and bottom by 2: 3/4.
4. Percent: 3/4 is 75 out of 100, or 75%.

Answer: 6 oktas, called broken. The clouds cover 3/4, or 75%, of the sky.

PRACTICE

1. EASY Name five things you should write beside every cloud photo in your journal.
2. EASY What is the cloud cover in oktas when the sky is completely clear? When it is completely covered? What are those two skies called?
3. EASY What did John Constable call his work of painting the sky over and over on Hampstead Heath, and what did he write on the backs of many studies?
4. MEDIUM Use the bar graph of 20 observations. (a) How many observations had a high cloud (a name beginning with cirr-) as the main type? (b) How many observations

showed a rain-bringing cloud (a name with nimbus)? (c) Which two cloud types tied? *(Use the map or drawing "Use the graph to answer." shown earlier in this lesson.)*

5. MEDIUM Hannah kept her journal for 12 days. It rained on 4 of them. What fraction of the days had rain? Write it in lowest terms.
6. MEDIUM Why should you take your journal photos from the same spot, facing the same direction, at the same times each day?
7. HARD Experiment design. Jacob wonders, "Is the sky cloudier in the afternoon than in the morning?" Plan his journal test. Tell (a) what changes, (b) three things to keep the same, (c) what to measure and (d) how many days he should record and why.
8. CHALLENGE Two journal entries: (1) "Tuesday 8 a.m., facing west: small flat-bottomed cumulus, 2 oktas, light wind." (2) "Friday 8 a.m., facing west: thin white streaks that by 4 p.m. had become a gray sheet with the sun dim behind it, 8 oktas." Name the cloud cover for each, and give a forecast for the next 12 hours for each with a reason.

COMMON MISTAKES

- Taking beautiful cloud photos but writing no date, time or direction. Without notes, a photo is a picture, not data.
- Deciding a pattern after one or two days. Patterns only show up after many observations, and even then they are clues, not promises.
- Pointing a camera or phone at the sun to catch a bright sky. This can hurt your eyes. Keep the sun out of the picture and out of your view.

Make it a game · Okta Pie. Cut a paper plate into 8 equal slices and color one side of each slice gray (cloud) and the other blue (sky). One player secretly turns some slices gray side up and covers the plate with a towel. The other player gets a 3-second peek and must call out the oktas and the name: clear, few, scattered, broken or overcast. One point for the right number and one for the right name. Then go outside and play it with the real sky, checking each other's estimates.

Scripture. "Who covereth the heaven with clouds, who prepareth rain for the earth, who maketh grass to grow upon the mountains." (Psalm 147:8, KJV)

Each page of your cloud journal records a little of what this verse describes: God covering the sky with clouds and sending rain to make the grass grow. Careful watching is a way of noticing His daily care.

Practice answers

1. Any five of: the date, the time, the direction you faced, the main cloud type, other clouds, the cloud cover in oktas, the wind, the weather at the time, and what weather came later.
2. 0 oktas is clear. 8 oktas is overcast.
3. He called it "skying." He wrote the date, the time of day, the direction he faced and the wind.
4. (a) 3. Cirrus is the only high cloud on the graph. (b) 1 (cumulonimbus). (c) Cirrus and stratus tied with 3 each.

5. 4/12 = 1/3 of the days.
6. So that the only thing that changes from one photo to the next is the sky. Then your comparisons are fair, and any difference you see comes from the weather, not from where or when you looked.
7. (a) The time of day: morning or afternoon. (b) The same spot, the same direction, the same two clock times every day, and the same way of judging cloud cover (oktas). (c) The cloud cover in oktas at each time. (d) At least 10 to 14 days, because one or two days could be unusual; many days show the real pattern. He can then compare the average oktas for mornings and afternoons.
8. (1) 2 oktas is few. Forecast: fair and dry, because small fair-weather cumulus that are few and far apart do not bring rain. (2) 8 oktas is overcast. Forecast: rain or snow is likely within hours, because cirrus thickened into altostratus during the day, the sequence that often comes before a long rain.

Unit 3 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) Who named the clouds in 1802? Give his three main cloud names and what each means in Latin.
2. (5 pts) Sort these clouds by their bases: Cloud A at 7,000 m, Cloud B at 3,000 m, Cloud C at 500 m. Write high, middle or low for each, and name one possible cloud type for each.
3. (5 pts) Decode the names nimbostratus and cirrocumulus. Tell what each looks like.
4. (5 pts) Put these clouds in the order they often appear before a long rain, and tell what changes about the clouds as they come: nimbostratus, cirrostratus, cirrus, altostratus.
5. (5 pts) At 11 a.m. on a summer day, the cumulus clouds are growing taller and taller, and by 1 p.m. one has a flat, spreading top. Name the cloud, give a forecast and tell one safety rule.
6. (5 pts) What makes a halo around the moon, and why is it a clue but not a promise of rain?
7. (5 pts) What is the dew point? Explain how dew forms on grass on a clear, calm night.
8. (5 pts) In a dew test, an open cloth gained 9 g and a covered cloth gained 3 g on the same night. How many times as much dew did the open cloth gain? What did William Charles Wells conclude from tests like this?
9. (5 pts) If all the clouds in the sky were pushed together, they would fill 2 of 8 equal slices. How many oktas is that, what is it called, and what fraction of the sky is covered?
10. (5 pts) You want to find out which cloud type appears most often over your home. Name three things you must keep the same in your journal, what you will record, and how you will show your results.

Unit project: my own cloud atlas

Make a small cloud atlas of your own sky, modeled on the International Cloud Atlas. Include at least six labeled photos or sketches of different cloud types from your two-week journal, each with its date, time, direction, cloud cover in oktas and the weather that followed. Add your word-part key, your cloud-levels diagram, your bar graph of all your observations, and your forecast test from Lesson 3.2 with the number you got right.

End with a page of writing: one pattern you found in your journal, one result from your dew test, and a few sentences on what Job 37:16 means to you now that you have watched the clouds so closely.

- **Accuracy**: Each cloud is named correctly and placed at the right level, and science words such as dew point and okta are used correctly.

- **Records**: Every photo or sketch has complete notes, observations were made from the same spot and times, and the tally and bar graph match the journal.
- **Reasoning**: The writing describes a real pattern from the data, explains the forecast results honestly, and names what was changed and kept the same in the experiments.
- **Care**: The atlas is neat, well organized and easy to read, with titled pages and labeled pictures.

Answer key

1. Luke Howard. Cirrus means a curl of hair (wispy high clouds), cumulus means a heap (puffy clouds) and stratus means spread out (flat layers). (He also used nimbus, a rain cloud.)
2. A: high (above 6,000 m), such as cirrus. B: middle (2,000 to 6,000 m), such as altocumulus or altostratus. C: low (below 2,000 m), such as stratus or stratocumulus.
3. Nimbostratus = rain + layer: a thick, dark gray, low layer that brings steady rain or snow. Cirrocumulus = high and icy + heaped: tiny white puffs high in the sky, like grains of rice or fish scales.
4. Cirrus, cirrostratus, altostratus, nimbostratus. The clouds get thicker, lower and darker until the rain begins.
5. Cumulonimbus with an anvil top. Forecast: a thunderstorm soon, with heavy rain and possibly lightning, hail and strong gusts. Safety: go indoors when you hear thunder and stay in until 30 minutes after the last thunder.
6. Moonlight bending through the ice crystals of a thin cirrostratus cloud. It often means a storm system is coming, with rain or snow within a day or two, but sometimes the clouds thin out again and no rain falls, so it is a clue to check with other clues.
7. The dew point is the temperature to which air must cool for its water vapor to condense into liquid. On a clear, calm night the grass gives off heat to the sky and cools. When it cools to the dew point, the water vapor in the air touching it condenses into drops of dew.
8. 9 ÷ 3 = 3 times as much. Wells concluded that dew does not fall from the sky; it forms where surfaces cool by losing heat to a clear sky, and a cover (or clouds) sends heat back so less dew forms.
9. 2 oktas, called few. 2/8 = 1/4 of the sky is covered.
10. Keep the same spot, the same direction and the same times each day (and the same way of naming clouds and measuring oktas). Record the date, time, main cloud type and cloud cover for every observation over 10 to 14 days. Show the results with a tally and a labeled bar graph.

UNIT 4

Storms

Elihu told Job, “Out of the south cometh the whirlwind: and cold out of the north” (Job 37:9). Storms are some of the most powerful things in God’s creation, and they come from the same simple ingredients you studied in the first three units: water, air pressure and clouds. Warm, moist air rises, pressure falls, winds rush in, and sometimes the result is a hurricane hundreds of kilometers wide, a tornado no wider than a few houses, or a blizzard that buries whole cities.

In this unit you will stand with Isaac Cline on the beach at Galveston in 1900 as the sea rises against the wind. You will look over the shoulders of two Air Force officers in Oklahoma in 1948 as they make the first successful tornado forecast. You will walk the snowed-in streets of New York in the Great Blizzard of 1888, and you will follow Benjamin Franklin as he learns that lightning is electricity and invents the lightning rod to protect his neighbors.

Every story ends the same way: people watched carefully, learned from what happened and found ways to keep others safe. You will build a storm surge in a pan, a tornado in a bottle and a blizzard clothing test, read scales and graphs, and finish by writing and practicing a real storm plan for your own family.

BEFORE YOU BEGIN

- Knows the water cycle: evaporation, condensation and precipitation (Unit 1)
- Can explain that warm air rises and that low air pressure often brings stormy weather (Unit 2)
- Can name a few cloud types, including the tall cumulonimbus thunderstorm cloud (Unit 3)
- Can add, subtract, multiply and divide whole numbers and read a simple bar graph

MASTERY CHECKLIST

- I can tell the story of the Galveston hurricane and explain why the storm surge was the deadliest part.
- I can name the parts of a hurricane and use the Saffir-Simpson scale to find a hurricane’s category.
- I can explain how a tornado forms, rate one on the EF scale, and tell the difference between a watch and a warning.
- I can define a blizzard by its wind and visibility and explain wind chill and why layers keep me warm.
- I can estimate the distance to lightning by counting from flash to thunder.
- I can explain my family’s storm plan and the safe action for each kind of storm.

OPTIONAL BOOKS AND RESOURCES

- **NOAA SciJinks** (https://scijinks.gov/): Free. Short articles, pictures and games from NOAA and NASA about hurricanes, tornadoes, lightning and other weather, written for students.
- **National Weather Service Weather Safety** (https://www.weather.gov/safety/): Free. Plain safety guides for thunderstorms and lightning, tornadoes, hurricanes, winter storms and floods. Use it with your parent for Lesson 4.4.
- **Ready.gov Kids (FEMA)** (https://www.ready.gov/kids): Free. Checklists and activities to help a family build an emergency kit and make a plan.

4.1 The Galveston Hurricane (1900) ★

OBJECTIVES

- Tell the story of the Galveston hurricane of September 8, 1900, and explain why the storm surge was the deadliest part.
- Name and describe the parts of a hurricane (eye, eyewall, rain bands) and explain why hurricanes form over warm ocean water.
- Use the Saffir-Simpson scale to sort hurricanes by wind speed and compare storm-surge heights with land heights.

Warm-up. Fill a baking pan halfway with water and set it on a towel. Blow steadily across the water from one end through a straw for 20 seconds while a helper watches the far end. What happens to the water at the far side of the pan? Now imagine that the "straw" is a wind as wide as a state, blowing for a whole day.

Video. Coming soon. Galveston hurricane of 1900 and how hurricanes form (eye, eyewall, storm surge) for kids: search NOAA, NOAA SciJinks, National Hurricane Center, NASA Goddard hurricane footage, SciShow Kids, Homeschool Pop (Alternate) and Texas history channels.

KEY TERMS

hurricane
A huge spinning storm that forms over warm ocean water and has steady winds of at least 119 km/h (74 mph).

eye
The calm, often clear center of a hurricane, where air sinks slowly.

eyewall
The ring of tall thunderstorm clouds around the eye, where the strongest winds and heaviest rain are.

storm surge
A dome of seawater pushed onto the shore by a storm's winds, raising the sea far above its normal level.

Saffir-Simpson scale
A scale from Category 1 to Category 5 that sorts hurricanes by their steady wind speed.

CORE IDEAS

The story. In 1900, Galveston, Texas, was one of the richest and busiest port cities in the South. It sat on a long, low island of sand in the Gulf of Mexico, and its highest ground was only about 2.7 meters (8.7 feet) above the sea. The local weatherman for the U.S. Weather Bureau was Isaac Cline. Early on Saturday, September 8, 1900, Cline noticed something

strange. The wind was blowing from the north, off the land, which should have pushed the water *away* from the beach. Instead, the tide kept rising and great waves rolled in. By afternoon the streets were flooding, and the barometer kept falling. That night a hurricane came ashore. Its winds tore off roofs, and the wind gauge on the Weather Bureau roof blew away.

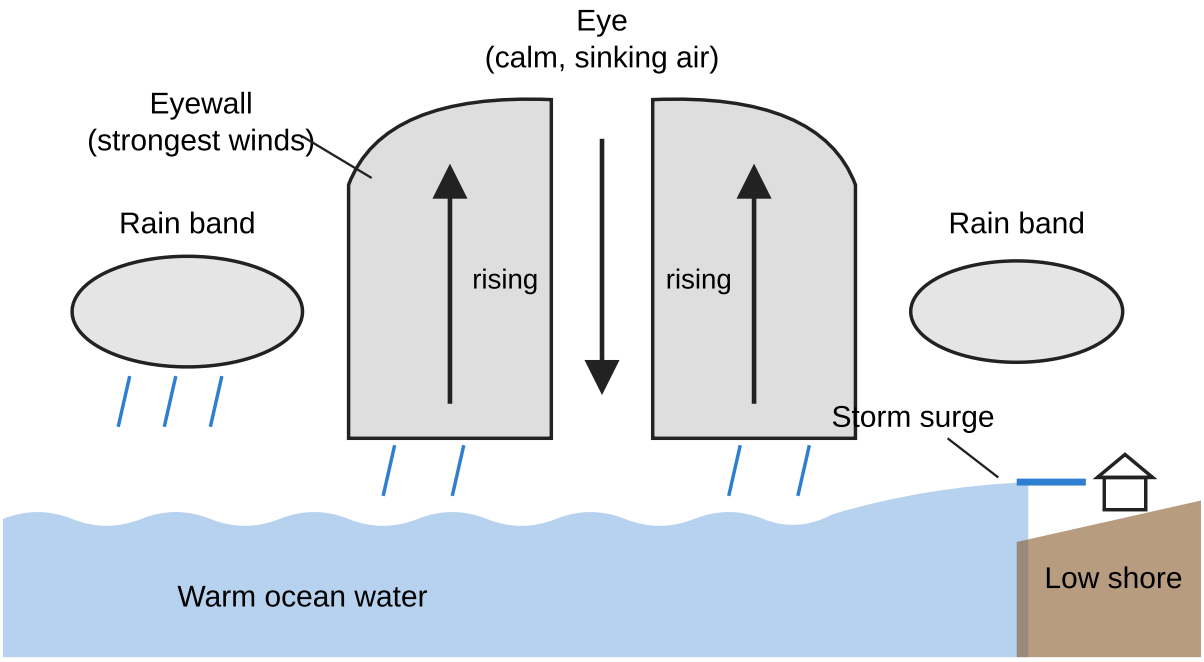
What the water did. The worst part was not the wind but the water. The storm pushed a wall of seawater, a **storm surge** of about 4.6 meters (15 feet) in places, right over the whole island. Houses broke apart and their wreckage battered the buildings still standing. At least 6,000 people died, and most historians think the number was about 8,000 or more. It is still the deadliest natural disaster in the history of the United States. Isaac Cline's own house fell. His wife, Cora, was lost, but Cline, his brother Joseph and his three daughters survived by clinging to floating wreckage through the night.

How they figured it out. In 1900 there were no satellites, no radar and no airplanes to fly into storms. Weathermen knew a storm had crossed Cuba, but they could not see where it was going over the open Gulf. The clues they had were the ones Cline watched: the rising tide, the long swells rolling in from far away, the falling barometer and the shifting wind. Today we know that the swells came from the storm's winds far out at sea, and that the falling pressure meant the low-pressure center was coming closer. Every good forecaster since has learned from Galveston to watch the sea as well as the sky.

The big idea. A **hurricane** is a giant spinning storm that is born over warm ocean water, at least about 26.5 °C (80 °F). Warm water evaporates into the air. As that moist air rises, the water vapor condenses into clouds and gives off heat, which makes the air rise even faster. More air rushes in along the sea to take its place, and the turning of the earth sets it spinning. North of the equator, hurricanes spin counterclockwise. In the middle is the calm **eye**. Around it is the **eyewall**, with the strongest winds, and spiral **rain bands** reach out for hundreds of kilometers. Scientists sort hurricanes on the **Saffir-Simpson scale** from Category 1 (119 to 153 km/h, or 74 to 95 mph) to Category 5 (252 km/h, or 157 mph, and up). The Galveston storm was probably a Category 4.

In the world today. The people of Galveston did not give up. Starting in 1902 they built a concrete **seawall** about 5.2 meters (17 feet) high along the Gulf side of the city. Then they did something amazing: they pumped sand from the bay and raised the ground of the city itself, jacking up more than 2,000 buildings, even a large church, so the sand could be poured underneath. When another strong hurricane struck in 1915, far fewer people died. Today hurricane hunters fly airplanes into storms, satellites watch every ocean, and the National Hurricane Center warns coasts days ahead.

God's handiwork. The same warm sea, rising air and turning earth that build hurricanes also carry rain to farms far inland. The storm is a reminder that the winds and waves are bigger than we are. When the disciples were afraid in a storm on the Sea of Galilee, Jesus "rebuked the wind, and said unto the sea, Peace, be still" (Mark 4:39). Wise people study the sea, prepare and warn their neighbors, and they trust the One whom the winds obey.



Parts of a hurricane. Warm, moist air rises in the eyewall, air sinks in the calm eye, and the wind piles seawater onto the shore as a storm surge.

PICTURE STUDY



Seeking Valuables in the Wreckage, Galveston, Texas, Keystone View Company (photographer not named), 1900 · Black-and-white photograph (from a stereograph card) · Library of Congress, Washington, D.C.

In the days after the storm, photographers came to Galveston to record what had happened. Their pictures were printed in newspapers and sold on cards all over the country and helped Americans understand how great the disaster was. Many people sent money, food and

supplies, and nurses came to help. Clara Barton, the founder of the American Red Cross, came to Galveston herself to lead the relief work.

In this picture a family searches the heap of boards and beams that was once a row of houses. Look at it slowly, the way a scientist studies evidence, and ask what it tells you about the wind and the water.

Look closely

- Find the tallest heap of wreckage. What was it made of before the storm?
- Look for any building still standing in the distance. Is it made of wood, brick or stone?
- Look at the boards and beams. Are they lying every which way, or do many of them point the same direction? What might that tell you about the water?
- Find the people. What are they looking for, and why might that work be dangerous?

Talk about it

1. What clues in the picture show that water, and not only wind, did the damage?
2. Why do you think the stone and brick buildings did better than the wooden houses?
3. If you lived in Galveston in 1900, what would you want the city to build so this would not happen again?

> **Safety first.** Work with water on a towel or outdoors and wipe up spills right away so no one slips. Do not use an electric fan or hair dryer near the water; make waves with a piece of cardboard instead.

EXPERIMENT: STORM SURGE IN A PAN: DOES A SEAWALL HELP?

You will build a small model island in a pan, make a “storm” push water onto it, and test whether a seawall keeps the town dry. Like a real scientist, you will change only one thing and measure the result.

You will need

- A large baking pan or plastic storage bin
- Sand, soil or modeling clay to make a sloping beach
- Water (about 3 cm, or a little over 1 inch, deep)
- Six small blocks or sugar cubes for houses
- A strip of stiff plastic or a row of building bricks for a seawall
- A piece of stiff cardboard for making waves
- A ruler, a marker and your science notebook

Steps

1. **Question:** Does a seawall keep model houses dry during a storm surge? Write your **prediction**.

2. Pile sand or clay at one end of the pan to make a low island that slopes up out of the water. Place six houses in a row on the island, 3 cm (about 1 inch) from the water’s edge.
3. Pour water into the other end until it is about 3 cm deep. Stick the ruler upright at the shore so you can read how high the water climbs.
4. **Trial without a seawall:** Push the cardboard back and forth at the far end 20 times, at the same speed each time, to make the “storm.” Count how many houses get wet or fall over, and mark the highest point the water reached.
5. Dry the houses, smooth the beach and set everything up exactly the same way again.
6. **Trial with a seawall:** Press the seawall into the sand between the water and the houses. Make the same 20 pushes at the same speed.
7. Do each trial two more times. Record every result in a table with columns: Trial, Seawall? (yes or no), Houses wet, Highest water mark (cm).

Tips

- **What we change:** seawall or no seawall. **What we keep the same:** water depth, number of pushes, speed of pushes, where the houses stand. **What we measure:** houses wet and how high the water climbed.
- Try a third test: raise the houses up on a higher mound of sand, the way Galveston raised its ground. Which helps more, the wall or the higher ground?

Check your work

- I can explain what a storm surge is.
- I changed only one thing at a time and kept everything else the same.
- I can use my data table to say whether the seawall helped.

FIELD NOTEBOOK

1. Draw a cross-section of a hurricane and label the eye, eyewall, rain bands, warm ocean water and storm surge. Add arrows to show air rising in the eyewall and sinking in the eye.
2. Draw Galveston Island before and after the seawall and grade raising. Show the sea level, the storm surge and the height of the ground with a little scale bar.
3. Write two sentences in your lab notebook about the clue Isaac Cline saw on the morning of September 8, 1900: rising water even though the wind blew off the land.

> **From history.** The Galveston storm of 1900 had no name. In those days storms were known by the place they struck or the year. The U.S. Weather Bureau began giving Atlantic hurricanes official names from a list in 1953, so that forecasters, ships and radio stations would not mix up two storms on the map at the same time. At first only women’s names were used; men’s names were added to the lists in 1979. Names of very deadly or costly storms are retired and never used again.

WORKED EXAMPLES

Example 1. Galveston's highest ground in 1900 was about 2.7 m (8.7 ft) above the sea. In places the storm surge raised the sea about 4.6 m (15 ft). How deep was the water over the highest ground?

(Use the map or drawing "The storm surge is a dome of seawater pushed ashore by the wind." shown earlier in this lesson.)

1. The water rose to 4.6 m above normal sea level. The ground was 2.7 m above sea level.
2. Subtract to find how much water stood above the ground: 4.6 m − 2.7 m = 1.9 m.
3. In feet: 15 ft − 8.7 ft = 6.3 ft.
4. Check: 1.9 m is taller than most grown men, so even the highest street was under deep water.

Answer: About 1.9 m (about 6 ft) of water covered even the highest ground.

Example 2. Use the Saffir-Simpson scale to find the category of a hurricane with steady winds of 225 km/h (140 mph). Category 1: 119–153 km/h (74–95 mph). Category 2: 154–177 km/h (96–110 mph). Category 3: 178–208 km/h (111–129 mph). Category 4: 209–251 km/h (130–156 mph). Category 5: 252 km/h (157 mph) or more.

1. Is 225 km/h at least 119 km/h? Yes, so it is a hurricane.
2. Go down the list. 225 is more than 208, so it is stronger than Category 3.
3. 225 is between 209 and 251, so it fits Category 4.
4. Check in mph: 140 is between 130 and 156. Category 4 again.

Answer: Category 4, the same category scientists think the Galveston storm reached.

PRACTICE

1. EASY What is the calm center of a hurricane called, and what is the ring of tall clouds around it called?
2. EASY What is a storm surge, and why was it the deadliest part of the Galveston hurricane?
3. EASY Why do hurricanes form over warm ocean water and not over cold water or dry land?
4. MEDIUM A hurricane has steady winds of 190 km/h (118 mph). Use the Saffir-Simpson scale in Worked Example 2 to find its category.
5. MEDIUM Read this table of steady wind speeds. Storm A: 95 km/h (59 mph). Storm B: 130 km/h (81 mph). Storm C: 215 km/h (134 mph). Storm D: 260 km/h (162 mph). Which storms are hurricanes, and what category is each one?

6. MEDIUM Galveston's seawall was built about 5.2 m (17 ft) high. The 1900 storm surge reached about 4.6 m (15 ft). How much higher is the seawall than that surge?
7. HARD Mia wants to test whether warm water evaporates faster than cool water, to understand why hurricanes need warm oceans. Plan her experiment: What one thing should she change? Name three things she should keep the same. What should she measure?
8. CHALLENGE On the morning of the storm, Isaac Cline saw the tide rising even though the wind blew from the land toward the sea. In two or three sentences, explain why this was a warning sign.

COMMON MISTAKES

- Thinking the storm is over when the eye passes. The eye is calm, but the other side of the eyewall comes next with winds blowing hard from the opposite direction. Stay inside until officials say the storm has passed.
- Thinking wind is the most dangerous part of a hurricane. Water from the storm surge and flooding rain usually causes the most deaths, as it did at Galveston.
- Thinking a hurricane is just a big thunderstorm. It is a whole system of thunderstorms, hundreds of kilometers wide, spinning around a low-pressure center and fed by warm ocean water.

Make it a game · Hurricane Category Race. Write the five Saffir-Simpson categories and their wind speeds in km/h on five cards and lay them out in order. Your parent calls out a wind speed, such as "200 kilometers per hour!" Race to stand on (or touch) the right card. If the speed is under 119 km/h, shout "Not a hurricane!" Score a point for each correct answer, and a bonus point if you can also name one part of a hurricane (eye, eyewall, rain band or storm surge). Play to ten points.

Scripture. "He maketh the storm a calm, so that the waves thereof are still." (Psalm 107:29, KJV)

Psalm 107 describes sailors tossed by a great storm who cry to the Lord. The winds and waves of a hurricane are far stronger than any person, but they are not stronger than God. We study storms and prepare for them, and we pray to the One who can still them.

Practice answers

1. The calm center is the eye. The ring of tall clouds with the strongest winds is the eyewall.
2. A storm surge is seawater pushed onto the shore by a storm's winds, raising the sea far above normal. At Galveston it covered the whole low island, broke apart houses and swept people away.
3. Warm water (at least about 26.5 °C, or 80 °F) evaporates quickly and gives the storm moist air. When that moisture condenses into clouds, it releases heat that makes the air rise faster and keeps the storm going. Cold water and dry land cannot feed it.
4. Category 3, because 190 km/h is between 178 and 208 km/h (118 mph is between 111 and 129 mph).

5. Storm A is not a hurricane (it is below 119 km/h, so it is a tropical storm). Storm B is Category 1. Storm C is Category 4. Storm D is Category 5.
6. 5.2 m − 4.6 m = 0.6 m (17 ft − 15 ft = 2 ft) higher.
7. Change: the starting temperature of the water (warm in one cup, cool in the other). Keep the same: the amount of water, the size and shape of the cups, where the cups sit (same room, same light), and how long she waits. Measure: how much water is left (or how far the water level dropped, in millimeters) after a set time, such as 24 hours.
8. A wind from the land should push water away from the beach and make the tide lower. If the water was rising anyway, something much stronger out at sea was pushing it in: the winds of a great storm piling up water and sending long swells ahead of it. That meant a storm surge was coming.

4.2 Tornadoes

OBJECTIVES

- Tell how Ernest Fawbush and Robert Miller made the first successful tornado forecast at Tinker Air Force Base, Oklahoma, on March 25, 1948.
- Explain how a tornado forms from a rotating thunderstorm and tell the difference between a tornado watch and a tornado warning.
- Use the Enhanced Fujita (EF) scale to rate tornadoes and calculate how much warning time a town has before a tornado arrives.

Warm-up. Fill a clear jar or tall glass with water. Stir it fast in a circle with a spoon for 10 seconds, pull the spoon out, and drop in a pinch of pepper or a few bits of torn paper. Watch from the side. What shape does the spinning water make in the middle? Where does it spin fastest?

Video. Coming soon. How tornadoes form, supercell thunderstorms, tornado watch vs. warning, and the 1948 Tinker Air Force Base forecast: search NOAA, NOAA SciJinks, National Severe Storms Laboratory, National Weather Service, SciShow Kids, Homeschool Pop (Alternate), Science Max and real storm-chaser footage from NOAA research teams.

KEY TERMS

tornado
A violently spinning column of air that reaches from a thunderstorm cloud down to the ground.

supercell
A large, long-lasting thunderstorm with a rotating updraft. Most strong tornadoes come from supercells.

funnel cloud
A spinning, cone-shaped cloud hanging from a storm that has not touched the ground. If it touches down, it is a tornado.

tornado watch
A message that the weather is right for tornadoes to form in an area. Be ready.

tornado warning
A message that a tornado has been seen or shown on radar. Take shelter now.

Enhanced Fujita (EF) scale
A scale from EF0 to EF5 that rates a tornado by estimating its winds from the damage it leaves.

CORE IDEAS

The story. On the night of March 20, 1948, a tornado roared across Tinker Air Force Base near Oklahoma City. No one had warned the base. The storm smashed dozens of airplanes and buildings. The commander ordered two Air Force weather officers, Major Ernest Fawbush and Captain Robert Miller, to find out whether such storms could ever be forecast. In those days most scientists thought tornadoes were too small and too sudden to predict.

How they figured it out. Fawbush and Miller studied the weather maps from the days before the storm. They looked at the warm, moist air flowing north from the Gulf of Mexico, the dry air above it, and the strong winds high in the sky. On the morning of March 25, only five days later, they looked at the new maps and could hardly believe it: the pattern was almost the same. In the afternoon they warned the base that a tornado might strike. Crews tied down planes and moved them into hangars. That evening a second tornado hit Tinker! Because of the warning, the base was ready and no one was killed. It was the first successful tornado forecast, and it changed weather science.

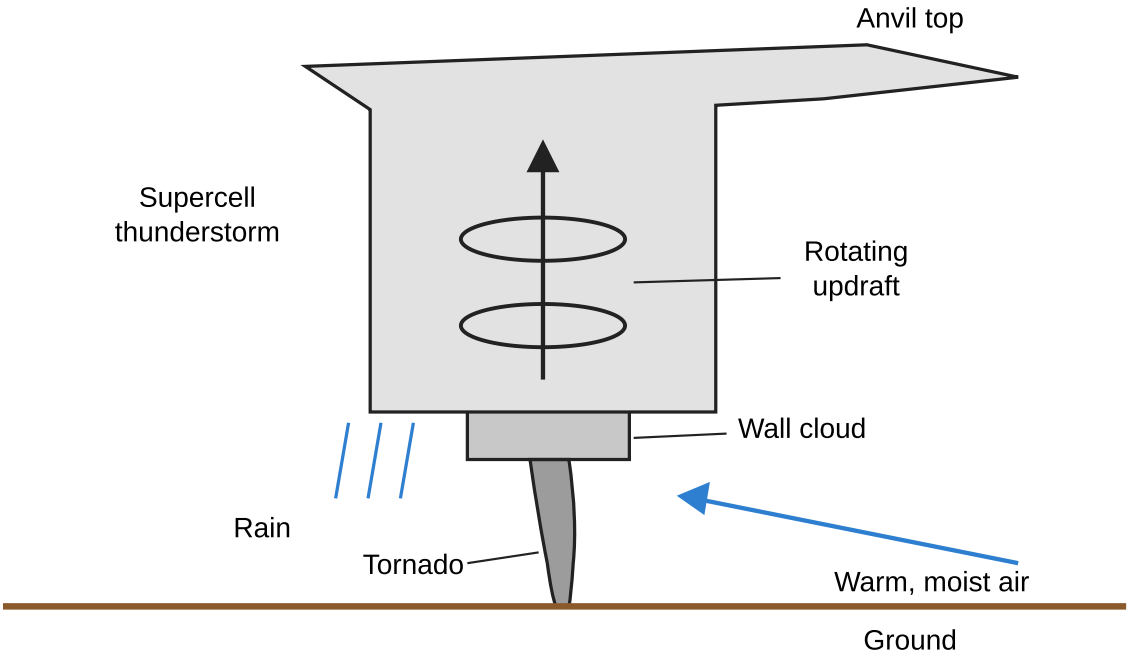
The big idea. A **tornado** is a violently spinning column of air that stretches from a thunderstorm down to the ground. Most strong tornadoes come from **supercells**, giant thunderstorms that turn slowly as they grow. They need warm, moist air near the ground, cooler, drier air above, and winds that change speed and direction as you go higher. Those changing winds set the air rolling, and the storm's powerful updraft tips the rolling air on end so it spins upward. Sometimes the spin tightens into a narrow funnel. When a **funnel cloud** touches the ground, it is a tornado. Most tornadoes in the Northern Hemisphere spin counterclockwise, like hurricanes, but they are far smaller: many are less than 100 meters (about 300 feet) wide and last only a few minutes.

Measuring the invisible. No one can safely put a wind gauge in the path of a tornado, so in 1971 a scientist named Ted Fujita at the University of Chicago made a scale that rates tornadoes by the *damage* they leave. Today the United States uses the **Enhanced Fujita scale**. An EF0 (105 to 137 km/h, or 65 to 85 mph) peels shingles and breaks branches. An EF5 (more than 322 km/h, or 200 mph) can sweep a strong house off its foundation. Most tornadoes are weak EF0 or EF1 storms. The United States has more tornadoes than any other country, about 1,200 a year, most of them in spring and early summer on the Great Plains and in the South.

In the world today. The National Weather Service now does every day what Fawbush and Miller did once. A **tornado watch** means the weather is right for tornadoes: be ready. A **tornado warning** means a tornado has been seen or shows on radar: take shelter now. Doppler radar can see winds spinning inside a storm, and on a radar map that spin often makes a curl called a hook echo. Warnings give families minutes to get to the lowest floor, into a small room without windows, and under something sturdy.

God's handiwork. Job heard God speak "out of the whirlwind" (Job 38:1), and Elihu said, "Out of the south cometh the whirlwind" (Job 37:9). The Bible does not pretend that storms are small. Yet God also gave people minds to notice patterns and the kindness to warn their

neighbors. Two officers studying weather maps on a spring morning saved lives by paying careful attention.



A supercell thunderstorm. Warm, moist air flows in near the ground, rises in a rotating updraft, and a tornado can drop from the wall cloud.

PICTURE STUDY



The earliest known photograph of a tornado, A. A. Adams, April 26, 1884 · Photograph · Taken at Garnett, Kansas; the picture survives in old books and journals

On the afternoon of April 26, 1884, a tornado formed about 14 miles west of the small town of Garnett, Kansas. A fruit grower named A. A. Adams, who had once run a photography studio and still owned his camera, set it up on a street corner near a church and made a picture of the funnel while it hung in the distance. People said the funnel stayed in sight for close to half an hour, which gave him time, because cameras then were slow and had to be held very still. It is believed to be the earliest surviving photograph of a tornado.

The picture is plain and faint, but that is what a far-off, dying tornado really looks like. Another, more dramatic photograph from the Dakota Territory in August 1884 was famous for many years as the first, but historians now think it was touched up. Scientists still use photographs and video to measure the size, shape and speed of tornadoes.

Look closely

- Find where the funnel reaches toward the ground. Is it wide or narrow there?
- Follow the funnel up to the cloud. Does it go straight up, or does it bend?
- Look at the land. Is it flat or hilly? Why might open prairie be a good place to see a tornado from far away?
- Find something in the picture that helps you judge how far away the tornado is.

Talk about it

1. Why do you think it took so long for anyone to photograph a tornado?
2. Would you have stayed to take this picture? What should a person do instead when a tornado is near?
3. What could a scientist learn from this photograph that is hard to learn from a story told by a frightened witness?

> **Safety first.** Use plastic bottles only, never glass. Tape the bottles tightly and work over a sink, a bucket or outdoors so water does not spill on the floor.

EXPERIMENT: TORNADO IN A BOTTLE: DOES A SPIN CHANGE THE FLOW?

You will connect two bottles and make a whirling “tornado” of water. Then you will test whether giving the water a spin changes how fast it drains from the top bottle to the bottom one.

You will need

- Two clean, empty 2-liter plastic bottles with the labels removed
- Water and a few drops of food coloring (optional)
- A pinch of glitter or a few bits of torn paper (optional, to see the spin)
- A metal washer about as wide as the bottle mouth
- Strong tape such as duct tape (or a plastic tornado-tube connector)
- A stopwatch or clock with a second hand, and your science notebook

Steps

1. **Question:** Does spinning the water make it drain faster or slower? Write your **prediction**.
2. Fill one bottle about two-thirds full of water. Add coloring and glitter if you like.
3. Set the washer on the mouth of the full bottle. Turn the empty bottle upside down on top so the mouths line up, and wrap them tightly with tape.
4. **Trial without a spin:** Flip the bottles so the full one is on top and set them straight up on a table. Start the stopwatch. Stop it when all the water has drained. Record the time.
5. **Trial with a spin:** Flip the bottles again. This time quickly swirl the top bottle in small circles 5 times, then set it straight up and hold it still. Time the draining. Watch for the funnel.
6. Do three trials of each kind. Record them in a table with columns: Trial, Spin? (yes or no), Seconds to drain. Find the average of each kind by adding the three times and dividing by 3.

Tips

- **What we change:** spin or no spin. **What we keep the same:** the same bottles, the same amount of water, the same number of swirls. **What we measure:** seconds to drain.
- In the spinning bottle, air can rise up the hollow center of the funnel while water pours down around it. Watch for the hole in the middle of your tornado.
- A real tornado is air, not water, but both are fluids, and both spin faster as they squeeze into a narrow column.

Check your work

- I made a vortex and saw the hollow center.
- I timed three trials of each kind and found the averages.
- I can explain the difference between a tornado watch and a tornado warning.

FIELD NOTEBOOK

1. Draw a supercell thunderstorm with its anvil top, rotating updraft, wall cloud and tornado. Add an arrow for warm, moist air flowing in.
2. Make a two-column chart titled “Watch or Warning?” and write what each means and what your family should do for each.
3. Copy the EF scale (EF0 to EF5 with speeds in km/h and mph) into your notebook, and beside each level draw a tiny picture of the kind of damage it causes.

> **From history.** In the 1880s an Army Signal Corps officer named John Park Finley collected hundreds of tornado reports and tried to forecast tornadoes. But for many years afterward, weather forecasters were told not to use the word “tornado” in public forecasts, because officials feared it would cause panic. After the success of Fawbush and

> Miller, the Weather Bureau began issuing public tornado forecasts in the early 1950s, and the system of tornado watches and warnings grew from there.

WORKED EXAMPLES

Example 1. After a tornado, scientists study the damage and estimate the strongest winds were about 180 km/h (112 mph). What is the tornado's EF rating? EF0: 105–137 km/h (65–85 mph). EF1: 138–177 km/h (86–110 mph). EF2: 178–217 km/h (111–135 mph). EF3: 218–266 km/h (136–165 mph). EF4: 267–322 km/h (166–200 mph). EF5: more than 322 km/h (more than 200 mph).

1. Start at the bottom. 180 km/h is more than 137, so it is stronger than EF0.
2. 180 is more than 177, so it is stronger than EF1.
3. 180 is between 178 and 217, so it fits EF2.
4. Check in mph: 112 is between 111 and 135. EF2 again.

Answer: EF2, a strong tornado that can tear roofs off houses and snap large trees.

Example 2. A tornado is moving toward a town at 50 km/h (about 30 mph). Radar shows it is 25 km (about 15 miles) away. How many minutes does the town have to take shelter?

1. Time = distance ÷ speed.
2. 25 km ÷ 50 km per hour = 0.5 hour.
3. One hour is 60 minutes, so 0.5 hour = 30 minutes.
4. Check in miles: 15 miles ÷ 30 miles per hour = 0.5 hour = 30 minutes.

Answer: About 30 minutes, if the tornado keeps the same speed and direction. Real tornadoes can speed up or turn, so people should take shelter as soon as the warning comes.

PRACTICE

1. EASY What is the difference between a funnel cloud and a tornado?
2. EASY Your radio says, "The National Weather Service has issued a tornado watch for our county." Should you run to shelter right now? What should you do?
3. EASY During a tornado warning, where is the safest place in a house without a basement?
4. MEDIUM Scientists estimate a tornado's winds were 300 km/h (186 mph). Use the EF scale in Worked Example 1 to rate it.
5. MEDIUM A weather club made this practice table of tornadoes seen in one state over one year. March: 4. April: 11. May: 16. June: 9. July: 3. (a) Which month had the most tornadoes? (b) How many tornadoes were there in all five months? (c) How many more were there in May than in July?

6. MEDIUM A tornado is 12 km (about 7.5 miles) from a farm and moving toward it at 36 km/h (about 22 mph). How many minutes until it arrives?
7. HARD Sam wants to know whether the amount of water in a tornado bottle changes how long the water takes to drain. Plan his experiment. What will he change? What must he keep the same? What will he measure? Why should he do more than one trial?
8. CHALLENGE Before 1948, many scientists thought tornadoes could never be forecast. In three or four sentences, explain how Fawbush and Miller proved them wrong and why their method still matters.

COMMON MISTAKES

- Thinking you should open windows to “let the pressure out.” This wastes precious time and does not help. Get to shelter instead.
- Thinking a highway overpass is a safe place to hide. Wind speeds can be even higher under an overpass, and flying objects blow through it. A sturdy building or a ditch, lying flat and covering your head, is safer.
- Thinking tornadoes never hit cities, hills, rivers or valleys. Tornadoes can cross all of these. No place is protected by its shape or size.

Make it a game · Watch or Warning?. Your parent reads a weather message out loud, such as “A tornado has been spotted 10 miles west of town!” or “Conditions are right for tornadoes this afternoon.” If it is a watch, shout “Get ready!” and touch your shoes and flashlight. If it is a warning, shout “Take cover!” and race to your family’s safe room, crouch and cover your head. Score a point for each right answer and a bonus point for getting to the safe spot in under 30 seconds. Play to ten points.

Scripture. “Out of the south cometh the whirlwind: and cold out of the north.” (Job 37:9, KJV)

Elihu noticed a pattern: whirlwinds come from the south, and cold comes from the north. On the American Plains, tornadoes often form when warm, moist air from the south meets cooler, drier air from the north and west. Careful watching of God’s world, the way Elihu and Fawbush and Miller did, helps us understand it and keep our neighbors safe.

Practice answers

1. A funnel cloud is a spinning cloud that has not touched the ground. When the spinning column reaches the ground, it is a tornado.
2. No. A watch means the weather is right for tornadoes. Get ready: keep listening, know where your shelter is, and have shoes, a flashlight and a radio ready. If a warning is issued, go to shelter right away.
3. A small room on the lowest floor in the middle of the house with no windows, such as a closet, bathroom or hallway. Crouch low, cover your head and neck, and get under something sturdy if you can.
4. EF4, because 300 km/h is between 267 and 322 km/h (186 mph is between 166 and 200 mph).

5. (a) May, with 16. (b) 4 + 11 + 16 + 9 + 3 = 43 tornadoes. (c) 16 − 3 = 13 more in May.
6. 12 ÷ 36 = 1/3 of an hour. One third of 60 minutes is 20 minutes.
7. Change: the amount of water (for example 0.5 liter, 1 liter and 1.5 liters). Keep the same: the same bottles and washer, the same number of swirls, the same person swirling, holding the bottle straight. Measure: the seconds it takes to drain. Several trials show whether a result was luck or a real pattern, and he can average them.
8. Fawbush and Miller studied the weather maps from before the March 20 tornado and found the conditions that came before it: warm, moist air near the ground, dry air above and strong winds aloft. When the same pattern appeared on March 25, they warned the base, and a tornado struck that evening. They showed that you cannot predict the exact spot a tornado will touch down, but you can predict the days and places where tornadoes are likely. That is what a tornado watch does today.

4.3 Blizzards: The Great Blizzard of 1888

OBJECTIVES

- Tell the story of the Great Blizzard of March 1888 and explain how it changed New York City.
- Define a blizzard by its wind, blowing snow and poor visibility, and explain wind chill and why layers of clothing keep us warm.
- Read a bar graph of snowfall and use a snow-to-water ratio to find how much water is in fallen snow.

Warm-up. Wet the back of one hand with a little water and leave the other hand dry. Blow hard across both hands, or wave a notebook at them like a fan. Which hand feels colder? Now blow across the wet hand while your parent covers it with a sock. What changed?

Video. Coming soon. The Great Blizzard of 1888, how blizzards and nor'easters form, wind chill and winter storm safety for kids: search NOAA, NOAA SciJinks, National Weather Service winter safety, Smithsonian, New York history channels, SciShow Kids and Homeschool Pop (Alternate).

KEY TERMS

blizzard
A winter storm with strong winds of at least 56 km/h (35 mph) and falling or blowing snow that makes it hard to see farther than 400 m (1/4 mile) for 3 hours or more.

visibility
How far you can see clearly through the air.

snowdrift
A deep pile of snow heaped up by the wind.

wind chill
How cold the air feels on bare skin when wind carries body heat away faster.

nor'easter
A strong storm along the East Coast of the United States whose winds blow in from the northeast, off the ocean.

CORE IDEAS

The story. On Sunday, March 11, 1888, the people of New York City went to bed listening to a cold rain. Spring was only days away. But in the night the rain turned to snow, the wind rose to a roar, and on Monday morning the city woke to a white wall. The snow did not fall gently. It blew sideways so hard that people could not see across the street. Drifts piled higher than the first floors of houses. The elevated trains stopped high above the streets, and

passengers had to climb down ladders. Telegraph and telephone poles snapped, and New York was cut off from the rest of the country. Some messages from New York to Boston had to be sent the long way, across the ocean to England by undersea cable and back again.

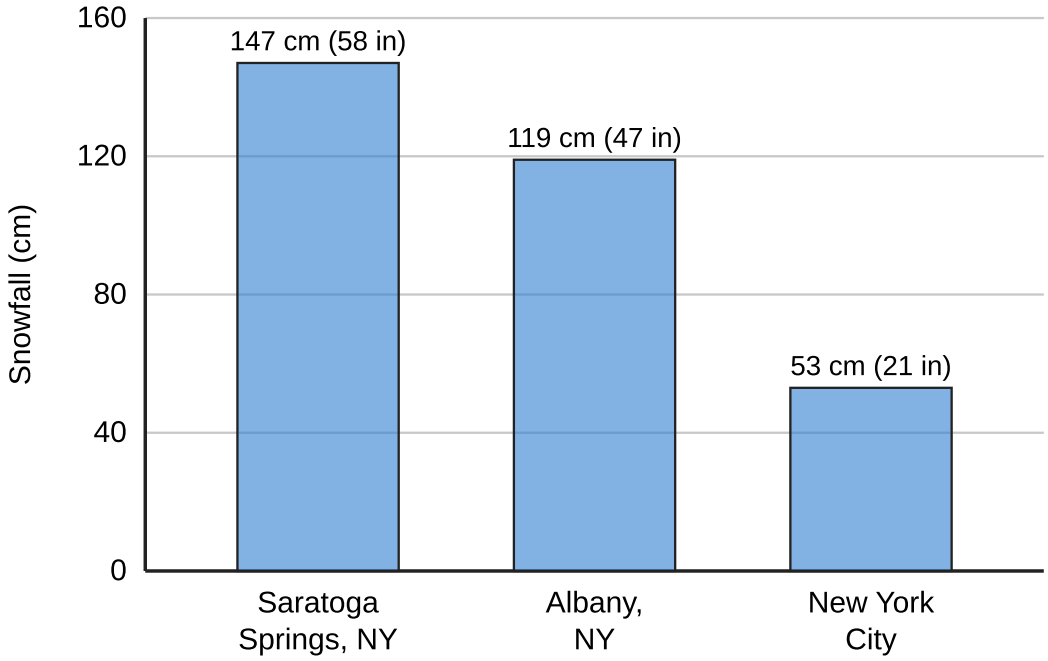
What it did. For about three days the storm buried the Northeast from Maryland to Maine. Saratoga Springs, New York, measured about 147 cm (58 in) of snow. New York City got about 53 cm (21 in), but the wind piled it into drifts taller than a two-story house. Former U.S. senator Roscoe Conkling tried to walk about 5 km (3 miles) home from his law office through the storm. He reached his club worn out and later died of an illness that followed. More than 400 people died in the storm, on land and on ships at sea. People named it the "Great White Hurricane."

How they figured it out. The forecasters of 1888 had expected rain and colder weather, not a great blizzard. Their reports came by telegraph, and the storm knocked out the very wires that carried them. Afterward, scientists studied the readings and found that two storms had joined: a low-pressure storm moving up the coast, pulling in moist air from the Atlantic, and very cold air pouring down from Canada. The great difference in pressure between them made the fierce winds. The city learned a practical lesson too. New York began moving its telegraph and telephone wires underground, and leaders pushed harder to build a subway that snow could not stop. It opened in 1904.

The big idea. A **blizzard** is not just a big snowfall. The National Weather Service calls a storm a blizzard when the wind blows at least 56 km/h (35 mph) and falling or blowing snow cuts **visibility** to less than 400 m (1/4 mile) for at least 3 hours. A blizzard needs three things: cold air, moisture to make snow, and a strong pressure difference to drive the wind. Wind is the danger. It piles **snowdrifts**, hides roads and makes people lose their way. It also steals heat from the body. The faster the air moves across your skin, the faster it carries away your warmth. That is **wind chill**. Frostbite can freeze fingers, toes, ears and noses, and hypothermia happens when the whole body gets too cold.

Try it and see. Clothing does not make heat. Your body does. Clothing traps still air, and still air is a poor carrier of heat, so it slows the heat from leaving. Several thin layers trap more air than one thick layer, and a windproof outer layer stops the wind from blowing the warm air away. Snow itself is full of trapped air, which is why rabbits and birds can stay warm under it.

God's handiwork. In 1885, three years before the great blizzard, a Vermont farm boy named Wilson Bentley became the first person to photograph a single snow crystal through a microscope. He photographed thousands more and found every one a beautiful six-sided pattern. The same snow that buried New York was made of billions of these tiny works of art.



Snowfall in three places during the Great Blizzard of March 1888, in centimeters (inches in parentheses).

PICTURE STUDY



Snow Storm – Steam-Boat off a Harbour's Mouth, J. M. W. Turner, 1842 · Oil on canvas · Tate Britain, London

Joseph Mallord William Turner was an English painter who loved storms, light and weather more than almost any artist before him. The full title of this painting tells a story: the steamboat is "making signals in shallow water, and going by the lead," which means the sailors were dropping a weighted line to measure the depth so they would not run aground. Turner added, "The Author was in this Storm on the Night the Ariel left Harwich." He later said that he had asked the sailors to tie him to the mast so he could watch the storm. Some

historians doubt that part of the tale, but the painting shows what it feels like to be inside a storm where you cannot see.

Many people in Turner's day did not like this painting. They said it was only a mess of paint. Today many people think it shows a blizzard's wind, snow and poor visibility better than a careful drawing could.

Look closely

- Find the steamboat's mast. How hard was it to find?
- Follow the swirl of snow, smoke and waves with your finger. Where does the swirl go?
- Look for the brightest spot in the painting. What do you think it is?
- Find any place where you can clearly tell the sky from the sea.

Talk about it

1. How does this painting show low visibility, one of the marks of a blizzard?
2. If you were a sailor on this boat, what would you be most afraid of?
3. Why do you think Turner painted the storm blurry instead of sharp?

> **Safety first.** Use warm tap water only, never boiling water or water from the stove. Use plastic jars or bottles if you can, and handle glass carefully.

EXPERIMENT: BLIZZARD CLOTHING TEST: WHICH WRAP KEEPS WARM LONGEST?

Travelers caught in a blizzard live or die by how well they keep their body heat. You will use jars of warm water as "bodies" and test which wrapping keeps them warm the longest.

You will need

- Four identical jars or plastic bottles with lids
- Warm tap water and a measuring cup
- A kitchen or outdoor thermometer
- One thin cotton cloth (an old T-shirt), one wool sock or sweater sleeve, and three thin cotton cloths for layers
- Rubber bands or tape
- A cold spot: a freezer, a refrigerator, a cold porch or the snow outside
- A clock and your science notebook

Steps

1. **Question:** Which wrapping keeps a jar of warm water warm the longest: nothing, one cotton layer, three cotton layers or wool? Write your **prediction**.
2. Fill all four jars with the same amount of warm tap water, such as 250 mL (about 1 cup). Measure the temperature of the water and write it down. It should be the same in every jar.

3. Leave jar 1 bare. Wrap jar 2 in one cotton cloth, jar 3 in three cotton cloths, and jar 4 in wool. Hold the wraps on with rubber bands. Close every lid.
4. Set all four jars side by side in the same cold spot.
5. After 30 minutes, open each jar and measure the water temperature.
6. Record your results in a table with columns: Jar, Wrapping, Starting temperature (°C), Temperature after 30 minutes (°C), Degrees lost. Find degrees lost by subtracting.

Tips

- **What we change:** the wrapping. **What we keep the same:** the jars, the amount and starting temperature of the water, the cold spot and the time. **What we measure:** how many degrees each jar lost. Jar 1, the bare jar, is the **control** that the others are compared with.
- For a windy test, set the jars in front of a fan in a cool room and see which wrap loses heat fastest in the wind. Then add a plastic bag over one wrap as a “windbreaker.”

Check your work

- I kept everything the same except the wrapping.
- I recorded my temperatures and subtracted to find degrees lost.
- I can explain why layers and a windproof outer coat keep a person warm in a blizzard.

FIELD NOTEBOOK

1. Draw a “blizzard checklist” picture with three parts: cold air, moisture and strong wind. Under it write the National Weather Service rule: wind of at least 56 km/h (35 mph), visibility under 400 m (1/4 mile), for 3 hours or more.
2. Catch a snowflake on a piece of dark cloth or paper that has been kept cold, look at it with a magnifying glass, and draw it quickly. Count its sides. (If you have no snow, draw a six-sided snow crystal from a picture of Wilson Bentley’s photographs.)
3. Draw yourself dressed for a blizzard. Label each layer and write what it does: traps warm air, stops the wind or keeps you dry.

> **From history.** Two months before the Great Blizzard, on January 12, 1888, another deadly blizzard struck the Great Plains of Nebraska, the Dakota Territory and nearby states. The morning had been unusually mild, so many children walked to school without heavy coats. In the afternoon a fierce cold front swept in with blinding snow and a sudden drop in temperature, just as school was letting out. More than two hundred people died, many of them children trying to get home, and it became known as the Children’s Blizzard. Some teachers kept their students safe by keeping them in the schoolhouse or leading them together to the nearest house.

WORKED EXAMPLES

Example 1. Use the bar graph. How much more snow fell at Saratoga Springs than in New York City during the Great Blizzard of 1888?

(Use the map or drawing "Snowfall in the Great Blizzard of 1888." shown earlier in this lesson.)

1. Read the bar for Saratoga Springs: about 147 cm (58 in).
2. Read the bar for New York City: about 53 cm (21 in).
3. Subtract: 147 cm − 53 cm = 94 cm.
4. In inches: 58 in − 21 in = 37 in.

Answer: About 94 cm (37 in) more snow fell at Saratoga Springs.

Example 2. Snow is mostly trapped air. On average, about 10 cm of fresh snow melts down to about 1 cm of water (a ratio of 10 to 1). If 50 cm (about 20 in) of snow falls, about how much water is in it?

1. The ratio means divide the snow depth by 10.
2. 50 cm ÷ 10 = 5 cm of water.
3. In inches: 20 in ÷ 10 = 2 in of water.
4. Check: 5 cm × 10 = 50 cm. Yes.

Answer: About 5 cm (2 in) of water. Wet, heavy snow holds more water than this, and light, fluffy snow holds less.

PRACTICE

1. EASY What two things must happen together for 3 hours or more for a storm to be called a blizzard?
2. EASY Why do several thin layers of clothing keep you warmer than one thin shirt?
3. MEDIUM A weather station recorded this practice data. Hour 1: wind 40 km/h, visibility 300 m. Hour 2: wind 60 km/h, visibility 200 m. Hour 3: wind 65 km/h, visibility 150 m. Hour 4: wind 58 km/h, visibility 250 m. Hour 5: wind 45 km/h, visibility 600 m. (a) Which hours had blizzard conditions (wind at least 56 km/h and visibility under 400 m)? (b) Was this storm a blizzard?
4. MEDIUM Using a 10-to-1 snow-to-water ratio, how much water is in 30 cm (about 12 in) of snow?
5. MEDIUM Use the bar graph. About how many times as much snow fell at Saratoga Springs (147 cm) as in New York City (53 cm)? Round to the nearest whole number.
6. HARD Leo wants to test whether wind makes a cup of warm water cool faster. Plan his experiment. What will he change? What must he keep the same? What will he measure? Which cup is his control?

7. HARD The air temperature outside is −10 °C (14 °F), and the wind chill is −20 °C (−4 °F). Your water bottle is outside. Can the water get colder than −10 °C because of the wind? Explain.
8. CHALLENGE In three or four sentences, explain how the Great Blizzard of 1888 changed New York City and why those changes made sense.

COMMON MISTAKES

- Thinking any heavy snowfall is a blizzard. A blizzard is defined by strong wind and poor visibility. A storm with a lot of snow but little wind is a heavy snowstorm, not a blizzard, and blowing snow with no new snow falling can still be a blizzard.
- Thinking wind chill makes objects colder than the air. Wind chill is about how fast people and animals lose heat; a car or a thermometer will not drop below the air temperature.
- Thinking a coat makes heat. Clothing only slows the loss of the heat your body makes, by trapping still air.

> **Make it a game · Blizzard or Not?.** Your parent describes a winter storm, such as “Heavy snow, light wind, you can see the end of the street” or “No new snow, wind 60 kilometers per hour, you can’t see the mailbox.” Hold up a white card for “Blizzard!” or a blue card for “Not a blizzard!” and give the reason. Score a point for each right answer with a correct reason. Bonus round: name one piece of clothing that traps air and one that stops the wind.

> **Scripture.** “For he saith to the snow, Be thou on the earth; likewise to the small rain, and to the great rain of his strength.” (Job 37:6, KJV)

Job 37 describes the weather as God’s work: the snow, the rain, the whirlwind and the cold. A blizzard reminds us how small we are, and Wilson Bentley’s snow crystals remind us that God’s care reaches even to each tiny flake.

Practice answers

1. Strong wind of at least 56 km/h (35 mph), and falling or blowing snow that cuts visibility to less than 400 m (1/4 mile).
2. Each layer traps still air between it and the next layer. Still air carries heat away slowly, so more trapped air means less body heat escapes.
3. (a) Hours 2, 3 and 4. Hour 1 had poor visibility but the wind was too weak; hour 5 failed on both. (b) Yes, just barely, because blizzard conditions lasted 3 hours in a row.
4. 30 ÷ 10 = 3 cm of water (12 ÷ 10 = 1.2 in).
5. 147 ÷ 53 is about 2.8, so about 3 times as much.
6. Change: wind or no wind (one cup in front of a fan, one in still air in the same room). Keep the same: the cups, the amount of water, the starting temperature, the room and the time. Measure: the water temperature every 5 minutes for 30 minutes. The cup in still air is the control.

7. No. Wind makes things lose heat faster, so the bottle cools down to −10 °C sooner, but it cannot get colder than the air around it. Wind chill describes how fast bare skin loses heat, which is why people and animals are in more danger than objects.
8. The blizzard snapped telegraph and telephone poles and cut New York off from other cities, and it stopped the elevated trains, leaving people stranded. Afterward, the city began moving wires underground, where wind and snow could not knock them down. Leaders also pushed to build a subway, which opened in 1904 and could keep running under the streets in bad weather. Both changes protected the city’s communication and travel from the next big storm.

4.4 Storm Safety Plan

OBJECTIVES

- Tell how Benjamin Franklin studied lightning and invented the lightning rod to protect houses, and explain why his kite experiment was dangerous.
- Name the safe action for each kind of storm in this unit (hurricane, tornado, blizzard, thunderstorm and flood) and the parts of a family storm plan and kit.
- Use the flash-to-thunder count to estimate how far away lightning is, and calculate how much water a family needs in an emergency kit.

Warm-up. Walk through your home with a parent and a notebook. Find the room on the lowest floor that is closest to the middle of the house and has no windows. Draw a quick map and put a star on it. Then find where your family keeps a flashlight. Does it work?

Video. Coming soon. Lightning safety, the flash-to-thunder count, Benjamin Franklin and the lightning rod, and making a family emergency plan and kit for kids: search NOAA, NOAA SciJinks, National Weather Service safety, Ready.gov Kids (FEMA), The Franklin Institute, SciShow Kids and Homeschool Pop (Alternate).

KEY TERMS

lightning rod
A metal rod on top of a building, joined by a wire to the ground, that gives lightning a safe path into the earth.

thunder
The sound made when lightning heats the air so fast that the air bursts outward.

emergency kit
A box or bag of supplies, such as water, food, a flashlight, a radio and first-aid items, ready to use when a storm cuts off power or travel.

evacuate
To leave an area that is in danger, such as a low coast before a hurricane, and go to a safer place.

shelter in place
To stay where you are, in the safest part of a building, until the danger passes.

CORE IDEAS

The story. In the 1700s, lightning set fire to houses, barns and church steeples all over Europe and America. Many people rang church bells during storms, hoping the sound would keep the lightning away. In Philadelphia, Benjamin Franklin wondered whether lightning was the same thing as the small electric sparks he made in his workshop. He noticed that sparks jumped most easily to sharp metal points. In the summer of 1752, he flew a silk kite with a

pointed wire into a thunderstorm, holding the string with a key tied near the bottom. When the threads of the string stood up and a spark jumped from the key to his knuckle, he knew: lightning is electricity.

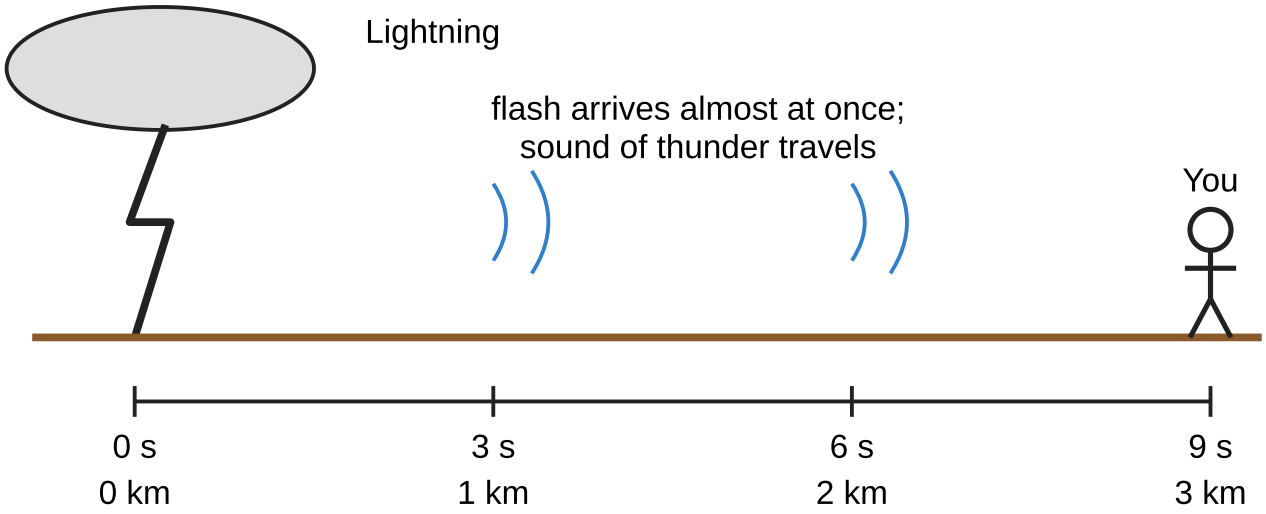
How they figured it out. Franklin did not stop at knowing. He wanted to protect his neighbors. In his almanac, *Poor Richard's Almanack*, for the year 1753, he told readers how to secure their houses from lightning. Put a pointed iron rod on top of the house, he wrote, and run a wire from it down the outside wall into the ground. When lightning strikes, it follows the metal safely into the earth instead of tearing through the roof. Lightning rods soon stood on houses, barns, ships and churches, and they still protect buildings today. But Franklin's kite was very dangerous, and you must never copy it. A real lightning bolt could easily have killed him.

The big idea. In this unit you have met four kinds of storms, and each one has its own safe action. **Thunderstorms:** when thunder roars, go indoors, because lightning can strike 16 km (10 miles) from a storm. Wait 30 minutes after the last thunder before going back out. **Tornadoes:** go to the lowest floor, in a small room without windows, and cover your head. **Hurricanes:** run from water and hide from wind. If officials tell your area to **evacuate**, leave early. **Blizzards:** stay indoors; if you are caught in a car, stay with the car. **Floods:** "Turn around, don't drown." About 15 cm (6 in) of fast-moving water can knock a grown-up down, and about 30 cm (1 ft) can carry away most cars.

Try it and see. You can tell how far away lightning is by counting. Light reaches you almost instantly, but sound is slower: it travels about 1 kilometer in 3 seconds (about 1 mile in 5 seconds). When you see a flash, count the seconds until you hear the thunder. Divide by 3 to get kilometers, or by 5 to get miles. If you can hear thunder at all, you are close enough to be struck, so the count is for learning, not for deciding to stay outside.

In the world today. A good family storm plan has a few simple parts. Know which storms happen where you live. Know how you will hear warnings: a weather radio, a phone alert, a siren or a radio station. Choose your safe room and a meeting place outside in case of fire. Write down the phone number of a relative in another town whom everyone can call. Pack an **emergency kit** with water (about 3.8 liters, or 1 gallon, per person per day, for at least 3 days), food that needs no cooking, a flashlight, extra batteries, a battery or hand-crank radio, a first-aid kit, medicines and a whistle. Then practice your plan, the way schools hold fire drills.

God's handiwork. Franklin's lightning rod did not stop the storm. It worked *with* the way God made lightning to behave, giving it an easier road to the ground. Wise planning is not fear. It is love for our families and neighbors, getting ready ahead of time so that when the storm comes we can act calmly.



The flash-to-thunder count. Sound travels about 1 km every 3 seconds (about 1 mile every 5 seconds).

PICTURE STUDY



The Life Line, Winslow Homer, 1884 · Oil on canvas · Philadelphia Museum of Art, Philadelphia

Winslow Homer was an American painter who loved the sea and the people who worked on it. In the 1880s he watched the men of the U.S. Life-Saving Service practice rescues on the New Jersey shore. When a ship ran aground near the beach in a storm, the lifesavers fired a rope out to it and rigged a *breeches buoy*, a ring and canvas seat that rode along the rope, so people could be carried over the waves to shore one at a time.

In this painting Homer shows one of those rescues in the middle of the storm. The lifesavers did not wait until the storm began to learn what to do. They drilled again and again in good weather so they would be ready in the worst.

Look closely

- Follow the rope. Where does it come from, and where is it going?
- Find the rescuer. Why do you think Homer hid his face with the blowing scarf?
- Look at the waves and the spray. How does Homer show the strength of the storm?
- Find the brightest colors in the painting. Where do they lead your eye?

Talk about it

1. Why did the Life-Saving Service practice its rescues over and over in calm weather?
2. How is a family storm drill like the lifesavers' practice?
3. Who in your town is ready to help when a storm comes?

> **Safety first.** Never fly a kite, climb a tree, swim or stand in an open field during a thunderstorm, and never copy Franklin's kite experiment. Stay out of flood water. During the drill, walk; do not run on stairs.

EXPERIMENT: OUR FAMILY STORM PLAN AND DRILL

You will make a real storm plan for your family, pack a simple kit, and test whether practice makes your family faster at reaching the safe room.

You will need

- Paper, pencil, colored pencils and your science notebook
- A box, tub or backpack for the kit
- Kit items your parent chooses: bottled water, canned or packaged food and a manual can opener, flashlight, extra batteries, battery or hand-crank radio, first-aid kit, whistle, a list of family phone numbers
- A stopwatch or a clock with a second hand

Steps

1. With your parent, list the storms that can happen where you live (thunderstorms, tornadoes, hurricanes, blizzards or floods).
2. For each one, write the safe action and where your family will go. Draw a map of your home and mark the safe room with a star and the outside meeting place with a flag.
3. Write the family contact card: an adult's phone number, a relative in another town, and your home address. Make a copy for every family member.
4. Pack the kit and make a checklist to tape on the lid. Calculate how much water your family needs for 3 days (see Worked Example 2).
5. **Question:** Does practice make our family faster at getting to the safe room? Write your **prediction**.
6. Run a tornado drill. Each person starts in the same place every time (for example, the kitchen, a bedroom and the porch). Someone calls "Tornado warning!" Start the

stopwatch, and stop it when everyone is crouched in the safe room with heads covered. Record the time.

7. Run the drill two more times. Record all three times in a table with columns: Drill number, Seconds to safe room, What slowed us down.

Tips

- **What we change:** the number of practices. **What we keep the same:** the starting places, the safe room and who is in the drill. **What we measure:** seconds to reach the safe room.
- Speed is good, but safety comes first. Walk quickly, do not run, and help younger children.
- Check the kit twice a year. Replace old batteries and food past its date.

Check your work

- Our family has a written plan, a map with a safe room and a meeting place, and a contact card.
- I packed a kit and calculated how much water we need.
- I timed three drills and can say whether practice made us faster.

FIELD NOTEBOOK

1. Draw a house with a lightning rod. Show the rod on the roof, the wire down the wall and the rod in the ground, and draw an arrow showing the lightning’s path.
2. Make a “Storm Safety Chart” with five rows: thunderstorm, tornado, hurricane, blizzard, flood. In each row draw one small picture and write the safe action.
3. During the next thunderstorm, watch safely from indoors. Count the seconds from flash to thunder for three flashes, write the times, and work out each distance in kilometers. Is the storm coming closer or moving away?

> **From history.** Franklin was fortunate. In the summer of 1753 a scientist named Georg Wilhelm Richmann in St. Petersburg, Russia, set up an iron rod to bring electricity from a thunderstorm into his laboratory so he could measure it. During a storm he leaned close to his instrument, and lightning traveled down the rod and killed him. He is remembered as the first person known to have died while doing an electrical experiment, and his death taught scientists everywhere that lightning must be led safely into the ground, never into a room or a person’s hands.

WORKED EXAMPLES

Example 1. You see a flash of lightning and count 9 seconds before you hear the thunder. About how far away was the lightning?

(Use the map or drawing "Count the seconds from flash to thunder, then divide by 3 for kilometers." shown earlier in this lesson.)

1. Sound travels about 1 km in 3 seconds.
2. 9 seconds ÷ 3 seconds per km = 3 km.
3. In miles: sound travels about 1 mile in 5 seconds, so 9 ÷ 5 = 1.8, about 2 miles.
4. Lightning can strike 16 km (10 miles) away from a storm, and 3 km is much closer than that.

Answer: About 3 km (about 2 miles) away. That is close enough to be struck, so go indoors right away.

Example 2. A family of 4 people is packing an emergency kit with enough water for 3 days. Each person needs about 3.8 liters (1 gallon) of water a day. How much water should they pack?

1. Find the water for one day: 4 people × 1 gallon = 4 gallons.
2. Find the water for three days: 4 gallons × 3 days = 12 gallons.
3. In liters: 12 × 3.8 L = 45.6 L, about 46 liters.
4. Check another way: 4 × 3 = 12 person-days, and 12 × 3.8 L = 45.6 L.

Answer: 12 gallons, about 46 liters of water.

PRACTICE

1. EASY What does "When thunder roars, go indoors" mean? How long should you wait after the last thunder before going back outside?
2. EASY Match each storm to its safe action. Storms: (a) tornado, (b) hurricane storm surge, (c) blizzard, (d) flooded road. Actions: (1) stay indoors, or stay with your car if caught in it; (2) turn around and find another way; (3) go to the lowest floor, in a small room without windows; (4) evacuate early when officials say to.
3. EASY How does a lightning rod protect a house?
4. MEDIUM You count 15 seconds between a flash and its thunder. How far away was the lightning in kilometers and in miles?
5. MEDIUM Ella counted flash-to-thunder times from indoors and made this table. 2:00 p.m.: 24 seconds. 2:05 p.m.: 18 seconds. 2:10 p.m.: 12 seconds. 2:15 p.m.: 6 seconds. (a) Find the distance in kilometers for each time. (b) Is the storm coming closer or moving away? (c) How many kilometers did it move every 5 minutes?

6. MEDIUM A family of 5 wants enough water for 3 days at 1 gallon (about 3.8 L) per person per day. How many gallons is that, and about how many liters?
7. HARD Grace wants to find which container keeps the family contact card dry best in a storm: a zipper bag, a plastic food box with a lid, or a paper envelope. Plan her test. What will she change? What will she keep the same? What will she measure?
8. CHALLENGE In three or four sentences, explain why families should make and practice a storm plan before a storm comes instead of deciding what to do when it arrives.

COMMON MISTAKES

- Thinking lightning never strikes the same place twice. It often strikes tall objects again and again; tall buildings are struck many times each year.
- Thinking the rubber tires make a car safe from lightning. A hard-topped car is safer because its metal body carries the electricity around the people inside and into the ground. A convertible or a bicycle gives no protection.
- Thinking you are safe from lightning if it is not raining yet. Lightning can strike many kilometers ahead of the rain, so go inside as soon as you hear thunder.

> **Make it a game · Storm Plan Scramble.** Your parent calls out a storm alert: "Thunder!" "Tornado warning!" "Hurricane evacuation!" "Blizzard!" or "Flooded road!" Within 10 seconds, act it out: go to a window-free spot and crouch for a tornado, grab the kit and head for the door for an evacuation, step inside for thunder, wrap up in a blanket for a blizzard, or turn around and walk the other way for a flood. Score a point for each right action. For a bonus, your parent claps for a flash and stomps for the thunder; count the seconds and say how many kilometers away the "lightning" was.

> **Scripture.** "A prudent man foreseeth the evil, and hideth himself: but the simple pass on, and are punished." (Proverbs 22:3, KJV)

A prudent, or wise, person sees trouble coming and gets to safety. A storm plan is a way of obeying this proverb: we look ahead, prepare, and go to shelter when the warning comes instead of ignoring it.

Practice answers

1. If you can hear thunder, you are close enough to be struck by lightning, so go inside a building or a hard-topped car right away. Wait 30 minutes after the last thunder before going back out.
2. (a) 3, (b) 4, (c) 1, (d) 2.
3. The pointed metal rod on the roof is joined by a wire to a rod in the ground. If lightning strikes, the electricity follows the metal safely down into the earth instead of going through the house and starting a fire.
4. 15 ÷ 3 = 5 km. 15 ÷ 5 = 3 miles.
5. (a) 24 ÷ 3 = 8 km, 18 ÷ 3 = 6 km, 12 ÷ 3 = 4 km, 6 ÷ 3 = 2 km. (b) It is coming closer. (c) About 2 km every 5 minutes.
6. 5 × 3 = 15 gallons. 15 × 3.8 = 57 liters.

7. Change: the kind of container. Keep the same: the same kind of paper card in each, the same amount of water sprayed or poured over each (for example 20 sprays from a spray bottle, or 1 minute under a sprinkling can), the same way of closing them, and the same waiting time. Measure: whether each card is dry, damp or soaked, or how many wet spots it has.
8. When a storm comes there is often very little time, sometimes only minutes for a tornado warning, and people who are frightened do not think clearly. If the family already knows the safe room, the meeting place and where the kit is, everyone can act quickly and calmly. Practice shows what slows the family down so they can fix it. Like the lifesavers in Homer’s painting, people who drill in calm weather are ready in the storm.

Unit 4 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) What is a storm surge? Why was it so deadly at Galveston in 1900?
2. (5 pts) Draw or describe the eye, the eyewall and the rain bands of a hurricane. Where are the strongest winds?
3. (5 pts) A hurricane has steady winds of 165 km/h (103 mph). Category 1: 119–153 km/h (74–95 mph). Category 2: 154–177 km/h (96–110 mph). Category 3: 178–208 km/h (111–129 mph). What category is it?
4. (5 pts) What is the difference between a tornado watch and a tornado warning? What should you do for each?
5. (5 pts) A tornado is 20 km (about 12 miles) away and moving toward a town at 40 km/h (about 25 mph). How many minutes does the town have?
6. (5 pts) How did Fawbush and Miller make the first successful tornado forecast in 1948?
7. (5 pts) Is every heavy snowstorm a blizzard? Explain using the National Weather Service definition.
8. (5 pts) In the Great Blizzard of 1888, Saratoga Springs got about 147 cm (58 in) of snow and New York City got about 53 cm (21 in). (a) How much more fell at Saratoga Springs? (b) Using a 10-to-1 ratio, about how much water was in New York City’s snow?
9. (5 pts) You count 12 seconds between a lightning flash and its thunder. How far away was it in kilometers? What should you do?
10. (5 pts) Ben tests which wrapping keeps a jar of warm water warm longest in the cold: no wrap, cotton or wool. Name what he changes, two things he keeps the same, what he measures, and which jar is the control.

Unit project: my storm science and safety book

Make a small illustrated book with one chapter for each storm: hurricanes, tornadoes, blizzards and thunderstorms with lightning. For each storm, draw and label a diagram, tell the true story from this unit (Galveston, Tinker Air Force Base, the Great Blizzard of 1888 or Franklin’s lightning rod), include one data table or graph from your experiments, and write the safe action in a bold box.

End the book with your family’s storm plan: the map of your home with the safe room and meeting place, the contact card, the kit checklist with your water calculation, and the times from your three drills with a sentence about what you learned.

- **Science**: Diagrams are correctly labeled (eye, eyewall, rain bands, storm surge, supercell, wall cloud, tornado), and the scales, definitions and explanations are accurate.

- **Data**: Each experiment has a question, a prediction, what was changed and kept the same, a neat data table or graph with units, and a conclusion.
- **Safety plan**: The family plan is complete, practical and practiced, with the safe action for every storm and correct kit calculations.
- **Care**: The book is neat, colorful and easy to read, with the true stories told in the student's own words.

Answer key

1. A storm surge is seawater pushed onto the shore by a storm's winds, raising the sea far above normal. Galveston was a low, flat island, its highest ground only about 2.7 m (8.7 ft) above the sea, so a surge of about 4.6 m (15 ft) covered the whole city, broke apart houses and swept people away.
2. The eye is the calm, often clear center where air sinks. The eyewall is the ring of tall thunderstorm clouds around the eye, with the strongest winds and heaviest rain. Rain bands are spiral bands of clouds and rain farther out. The strongest winds are in the eyewall.
3. Category 2, because 165 km/h is between 154 and 177 km/h (103 mph is between 96 and 110 mph).
4. A watch means the weather is right for tornadoes: get ready, keep listening and know where your shelter is. A warning means a tornado has been seen or shows on radar: take shelter right away in a small room on the lowest floor with no windows and cover your head.
5. 20 ÷ 40 = 0.5 hour = 30 minutes.
6. After a tornado struck Tinker Air Force Base on March 20, 1948, they studied the weather maps from before it and found the pattern that came first: warm, moist air near the ground, dry air above and strong winds high up. When the same pattern appeared on March 25, they warned the base, and a tornado struck that evening.
7. No. A blizzard needs wind of at least 56 km/h (35 mph) and falling or blowing snow that cuts visibility to less than 400 m (1/4 mile) for at least 3 hours. A heavy snow with little wind is not a blizzard.
8. (a) 147 − 53 = 94 cm (58 − 21 = 37 in). (b) 53 ÷ 10 = about 5.3 cm of water (21 ÷ 10 = about 2.1 in).
9. 12 ÷ 3 = 4 km (about 2.4 miles, using 12 ÷ 5). You are close enough to be struck, so go indoors right away and wait 30 minutes after the last thunder before going out.
10. He changes the wrapping. He keeps the same jars, amount of water, starting temperature, cold spot and time. He measures the water temperature at the end (or degrees lost). The jar with no wrap is the control.

UNIT 5

Forecasting

People have always wanted to know what tomorrow's weather will bring. Farmers need to know when to plant and harvest, fishermen when to put out to sea, and families when to plan a picnic. In this unit you will learn how a forecast is made: by observing carefully, recording honestly, finding patterns, and looking **upstream** to the place the weather is coming from. You will find that God made the sky orderly enough to read, and also that only He knows tomorrow for certain (James 4:14).

You will begin with Jesus' own words about red skies at evening and morning (Matthew 16:2–3) and discover why the saying often works. You will follow Samuel Morse's first telegraph message, "What hath God wrought," and see how Joseph Henry used the telegraph to make the first daily weather maps. You will meet the young Norwegian scientists who named **fronts**, and you will build a cold front of your own in a box of colored water. Finally, like James Stagg before D-Day, you will make a real 3-day forecast from your own instruments, check it day by day, and keep score.

BEFORE YOU BEGIN

- Can read a thermometer in °C and °F and knows that weather can be measured (Units 1–2)
- Knows that a falling barometer often means stormy weather and a rising one fair weather (Unit 2)
- Can name the main cloud types, including cirrus, altostratus, nimbostratus and cumulonimbus (Unit 3)
- Can divide a distance by a speed to find a time, such as 300 ÷ 25 = 12

MASTERY CHECKLIST

- I can explain Jesus' words about red skies and why a red evening sky often means fair weather where weather moves west to east.
- I can explain why the sky is blue at noon and red at sunset.
- I can tell how the telegraph made the first weather maps possible and read a simple weather map.
- I can name the four kinds of fronts, draw their symbols, and describe the weather a cold front and a warm front bring.
- I can make a 3-day forecast, check it against what really happened, and find its average error.
- I can explain what a "chance of rain" means and why forecasts for later days are less certain.

OPTIONAL BOOKS AND RESOURCES

- **NOAA SciJinks** (https://scijinks.gov/): Free. NOAA's weather site for students, with short articles, pictures and games about fronts, forecasts, weather maps and satellites. Good for reading together after each lesson.
- **National Weather Service JetStream: An Online School for Weather** (https://www.weather.gov/jetstream/): Free. Clear explanations of air masses, fronts and how to read weather maps. Written for older students and teachers, so a parent may read and explain the sections on fronts (Lesson 5.3).
- **National Weather Service forecasts** (https://www.weather.gov/): Free. Type in your town to get the official forecast and current weather map. Use it as the "official forecast" to compare with your own in Lesson 5.4.

5.1 Jesus on Red Skies (Matthew 16:2–3) ★

OBJECTIVES

- Read Matthew 16:2–3 and explain what Jesus said people knew about red skies at evening and in the morning.
- Explain why the sky turns red at sunrise and sunset and why weather in the middle latitudes usually moves from west to east.
- Test the “red sky” saying with a written record of observations and tell what fraction of the time it worked.

Warm-up. Go to a window or step outside with a parent. Using a compass, or by remembering where the sun went down last night, point to the west and then to the east. Now think: if clouds and rain usually travel from west to east, which side of the sky should you watch to see what tomorrow’s weather might be? Write your answer and one reason.

Video. Coming soon. Why sunsets are red and why “red sky at night” often works: search NOAA SciJinks, NASA Space Place, the UK Met Office, SciShow Kids, Science Max and Homeschool Pop for sunset color, light scattering and prevailing westerlies; add a time-lapse of a sunset over clouds.

KEY TERMS

forecast
A careful guess about future weather, based on what is observed now and on patterns seen before.

observation
Something you notice with your senses or measure with an instrument, and then write down.

scattering
When tiny bits of air bounce light off in many directions. Air scatters blue light much more than red light.

prevailing westerlies
The winds that usually blow from west to east across the middle latitudes, carrying weather systems with them.

lowring
An old English word (also spelled lowering) for a sky that is dark, heavy and threatening.

CORE IDEAS

The story. One day in Galilee, some Pharisees and Sadducees came to Jesus and asked Him to show them a sign from heaven. Jesus answered with something every farmer and

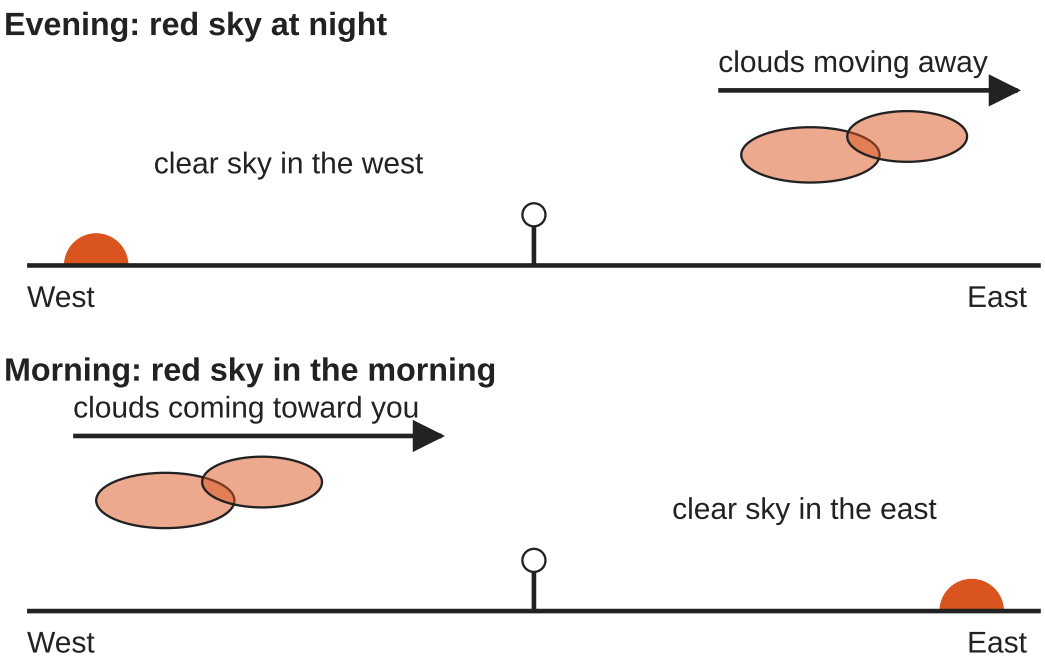
fisherman in the land already knew: “When it is evening, ye say, It will be fair weather: for the sky is red. And in the morning, It will be foul weather to day: for the sky is red and lowring” (Matthew 16:2–3). *Lowring* is an old word for a sky that is dark, heavy and threatening. Then Jesus said, “O ye hypocrites, ye can discern the face of the sky; but can ye not discern the signs of the times?” These men could read the clouds, yet they could not see who was standing right in front of them. Along the way, Jesus named a piece of real weather wisdom that we can still test today.

How they figured it out. Nobody needed a weather station to learn the saying. People in Israel watched the sky every day for generations, because their crops, flocks and fishing boats depended on it. They noticed that rain usually came in from the Mediterranean Sea, which lies to the west. In Luke 12:54 Jesus says, “When ye see a cloud rise out of the west, straightway ye say, There cometh a shower; and so it is.” Watching carefully, day after day, is how a pattern is found. That is still the first step in every science: observe, record, and look for what happens again and again.

The big idea. In the middle latitudes, the wide belt of the earth between the hot tropics and the icy poles, the winds high above usually carry weather from **west to east**. These winds are called the **prevailing westerlies**, and Israel and most of the United States lie under them. At evening the sun is in the west. If its light can shine through and color the sky, the western sky must be fairly clear, and that clear air is what is coming your way. In the morning the sun is in the east. If it lights up a bank of clouds red, those clouds are often in the west, the direction tomorrow’s weather comes from, so rain may be on its way. The saying is a *clue*, not a promise. Storms can come from other directions, and in the tropics the usual winds blow the other way.

Try it and see. Why is the sky red at all? Sunlight looks white, but it is really a mix of all the colors of the rainbow. When sunlight passes through air, the tiny bits of gas in the air bounce blue light off in every direction much more than red light. This is called **scattering**, and it is why the midday sky is blue. At sunrise and sunset the sun is low, so its light travels on a long, slanting path through much more air before it reaches you. By then most of the blue has been scattered away, and the reds and oranges are left to paint the clouds. You can watch this happen in a glass: shine a flashlight through slightly milky water, and the side of the glass looks bluish while the light coming out the far end looks orange.

God’s handiwork. The sky can be read because God made the world orderly. After the Flood He promised, “While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease” (Genesis 8:22). Winds follow patterns and light follows rules, so a child at a window can make a real forecast. Yet Jesus reminds us that reading the sky is not the most important kind of seeing. A good scientist watches the clouds carefully, and a wise person also watches for what God is doing.



Weather usually moves from west to east. A red evening sky means clear air in the west; a red morning sky often means clouds coming from the west.

PICTURE STUDY



Twilight in the Wilderness, Frederic Edwin Church, 1860 · Oil on canvas · Cleveland Museum of Art, Cleveland, Ohio

Frederic Edwin Church was an American painter who studied with Thomas Cole, the founder of the Hudson River School of landscape painters. Church was a man of faith who traveled far to paint God’s creation exactly, and he made careful sketches of clouds, light and

mountains. In this famous painting the sun has just gone down, and the whole sky is on fire with color above a still, empty wilderness.

Church painted it in 1860, the year before the Civil War began. Many people who saw it then felt both its beauty and a kind of quiet waiting, as if the land were holding its breath.

Look closely

- Find where the sun has gone down. Which way would that be: east or west?
- Look at the clouds high overhead. Why are they lit red and orange from underneath?
- Look at the sky near the horizon. Is it cloudy or clear there?
- Find the water. What is it reflecting?

Talk about it

1. Using Jesus' words in Matthew 16:2, what weather would the people in this wilderness expect tomorrow? Why?
2. Why do you think Church left people out of this painting?
3. Have you ever seen a sunset like this? What happened to the weather the next day?

> **Safety first.** Never look straight at the sun, even when it is low and red at sunset; look at the clouds and the sky around it. Do not shine the flashlight into anyone's eyes. Wipe up spilled milky water right away so no one slips.

EXPERIMENT: A SUNSET IN A GLASS

In this small experiment you will make your own "sky" out of water and a few drops of milk and find out why sunsets are red. The milk's tiny particles scatter light the way air does.

Question: Does adding more milk (more scattering) make the light that comes through the water look more orange and red? **Prediction:** Write yours before you begin.

You will need

- A tall clear glass or clear plastic jar holding about 500 mL (about 2 cups), or a clear plastic bottle laid on its side for a longer path
- Water
- Milk and a measuring spoon (about 2.5 mL, or 1/2 teaspoon)
- A flashlight with a small, bright beam
- A white index card or sheet of paper
- A dark room
- Notebook and colored pencils

Steps

1. Fill the glass with water. Make a table in your notebook with four columns: Spoons of milk, Color seen from the side, Color on the white card, Notes.

2. Darken the room. Shine the flashlight in through one side of the glass and hold the white card on the far side. Record the color on the card and the color you see looking at the glass from the side. This is your trial with 0 spoons of milk.
3. Add one 2.5 mL spoon (1/2 teaspoon) of milk and stir. Shine the light the same way, from the same distance. Record both colors.
4. Add a second spoon, stir and record. Then add a third spoon, stir and record.
5. Now shine the light through the *long* way (from the bottom up, or along a bottle on its side). Compare the color on the card with the short way.
6. Color a strip in your notebook for each trial showing what you saw, from white to yellow to orange.
7. Write two sentences: What happened to the light as you added more milk? How is this like sunlight at sunset?

Tips

- **What we change:** the amount of milk. **What we keep the same:** the water, the glass, the flashlight, and its distance from the glass. **What we measure:** the color of the light on the card.
- If the water becomes too cloudy to see any light come through, pour out half, add plain water and start the count again.
- Look for a faint blue tint when you look at the glass from the side. That is the scattered blue light, just like the blue of the daytime sky.

Check your work

- I kept everything the same except the amount of milk.
- I recorded the color for every trial.
- I can explain why light that travels a long way through air looks orange or red.

FIELD NOTEBOOK

1. Draw and color tonight's sky at sunset. Write the date, the time, which direction you faced, and whether the sky was red. Tomorrow, add a note telling what the weather was.
2. Copy Matthew 16:2–3 in your best handwriting and draw two small pictures beside it: a red evening sky and a red, lowring morning sky.
3. Draw the "Sunset in a Glass" setup with labels: flashlight, milky water, white card, blue side, orange end.

> **From history.** English-speaking sailors and shepherds kept Jesus' weather wisdom alive in a rhyme: "Red sky at night, sailor's delight; red sky in the morning, sailors take warning." In some parts of England the word is "shepherd's" instead of "sailor's." William Shakespeare used the same idea in his poem *Venus and Adonis*, published in 1593, where he compares a sad warning to a red morning that has always meant shipwreck for sailors and storms for the fields.

WORKED EXAMPLES

Example 1. Grace wrote down the sky at sunset for 10 evenings and the next day's weather. On 6 evenings the sky was red; on 5 of the next days it was fair and on 1 it rained. On the 4 evenings that were not red, the next day was fair 2 times and rainy 2 times. Did a red evening sky give a better clue to fair weather than a plain one?

1. Red evenings: fair the next day 5 times out of 6, so the fraction is 5/6.
2. Plain evenings: fair the next day 2 times out of 4, so the fraction is 2/4, which is 1/2.
3. To compare, make the bottoms the same. 5/6 = 10/12 and 1/2 = 6/12.
4. 10/12 is bigger than 6/12, so fair weather followed red evenings more often.
5. Ten evenings is a small sample, so Grace should keep recording to be more sure.

Answer: Yes. Fair weather followed a red evening 5 out of 6 times (10/12), but followed a plain evening only 2 out of 4 times (6/12). More days of records would make the result stronger.

Example 2. At 7 a.m. the rising sun lights a bank of clouds in the west a deep red. The weather radio says a band of rain is 300 km (about 190 mi) to the west, moving east at 25 km per hour (about 16 mph). About what time will the rain arrive?

(Use the map or drawing "A red morning sky often lights clouds that are coming from the west." shown earlier in this lesson.)

1. Time = distance ÷ speed.
2. 300 km ÷ 25 km per hour = 12 hours.
3. 7 a.m. + 12 hours = 7 p.m.

Answer: About 12 hours later, around 7 p.m. The red morning sky was a fair warning.

PRACTICE

1. EASY According to Matthew 16:2, what did people say when the sky was red in the evening?
2. EASY What does the KJV word "lowring" mean?
3. EASY In the middle latitudes, where Israel and most of the United States lie, which direction does weather usually travel?
4. MEDIUM Explain in two or three sentences why the sky is blue at noon but red and orange at sunset.
5. MEDIUM Sam kept this record for 14 mornings.
   Red morning sky: 4 mornings. Rain came within the day on 3 of them.
   Not red: 10 mornings. Rain came within the day on 2 of them.

(a) What fraction of red mornings were followed by rain? (b) What fraction of plain mornings? (c) Did a red morning give a useful warning in Sam’s record?

6. MEDIUM You want to test whether a red evening sky really means fair weather the next day. What is your variable? What will you compare it with? Name two things you must keep the same each time.
7. HARD In much of the tropics, the usual winds (the trade winds) blow from east to west. Would “red sky at night” work the same way there? Explain.
8. CHALLENGE At 6 a.m. a band of clouds lit red by the sunrise is 450 km (about 280 mi) west of your town, moving east at 30 km per hour (about 19 mph). Will the clouds arrive before supper at 6 p.m.?

COMMON MISTAKES

- Thinking the sun itself turns red at evening. The sun gives the same light all day; at sunset its light passes through much more air, which scatters the blue away.
- Thinking the sky is blue because it reflects the ocean. The sky is blue because air scatters blue sunlight; it is blue over deserts and mountains too.
- Treating “red sky at night” as a promise. It is a clue that works best where weather moves west to east, and a scientist checks it by keeping records.

> **Make it a game · Sky Detective.** A parent describes a sky in one sentence, such as “It is morning, and red clouds are piled up in the west,” or “It is evening, and the sun is setting in a clear, golden sky.” You have ten seconds to give a forecast for the next day and a reason that uses the words west, east, or scattering. A correct forecast with a good reason scores 2 points; a forecast without a reason scores 1. Switch roles after five turns.

> **Scripture.** “He answered and said unto them, When it is evening, ye say, It will be fair weather: for the sky is red. And in the morning, It will be foul weather to day: for the sky is red and lowring. O ye hypocrites, ye can discern the face of the sky; but can ye not discern the signs of the times?” (Matthew 16:2–3, KJV)

Jesus agreed that people could read the sky well. His deeper lesson was that they should pay even closer attention to what God was doing in front of them. Careful observing is good; seeing what matters most is better.

Practice answers

1. “It will be fair weather: for the sky is red.”
2. Dark, heavy, gloomy and threatening, as a sky looks before a storm.
3. From west to east, carried by the prevailing westerlies.
4. Air scatters blue light much more than red light, so at noon scattered blue light fills the sky. At sunset the sunlight travels a much longer, slanting path through the air, so most of the blue is scattered away before it reaches us, and mostly red and orange light is left.
5. (a) 3/4, which is 75 out of 100 (75%). (b) 2/10, which is 20 out of 100 (20%). (c) Yes. Rain followed red mornings much more often than plain ones, though 14 days is still a small record.

6. The variable is the color of the evening sky (red or not red). The result to record is the next day’s weather. Compare red evenings with evenings that were not red (the comparison, or control, group). Keep the same: the time you look (at sunset), the place you look from, the direction you face, and the same rule for what counts as “fair” (for example, no rain in the rain gauge). Record for several weeks.
7. Probably not. The saying works because the evening sky shows the west, where weather is coming from in the middle latitudes. Where weather usually comes from the east, a clear western sky at sunset does not tell you much about what is on its way.
8. No. 450 ÷ 30 = 15 hours, and 6 a.m. + 15 hours = 9 p.m. The clouds should arrive about 3 hours after supper.

5.2 The Telegraph and the First Weather Maps ★

OBJECTIVES

- Tell how Samuel Morse's telegraph and Joseph Henry's Smithsonian weather network let people see the weather of a whole country at once.
- Read a simple weather map with station symbols, temperatures and the direction a storm is moving.
- Use distance and speed to figure out when weather shown on a map will reach a town.

Warm-up. With a parent's help, call or message three relatives or friends who live in other towns and ask each one the same two questions at the same time: "What is your sky like right now?" and "Is it raining?" Write each town and its answer. Find the towns on a map. Which town is farthest west? Is its weather different from yours?

Video. Coming soon. Samuel Morse's telegraph and the beginning of weather maps: search the Smithsonian, the Library of Congress, NOAA history, the National Weather Service and Homeschool Pop for "What hath God wrought," how a telegraph key works, Joseph Henry's weather map and how to read a weather map station symbol.

KEY TERMS

telegraph
A machine that sends messages along a wire as quick pulses of electricity, tapped out as short and long signals.

Morse code
A code of dots (short signals) and dashes (long signals) that stand for letters and numbers.

weather station
A place where the weather is measured and recorded, often at the same times every day.

weather map
A map that shows the weather at many places at the same moment.

storm warning
A message sent ahead of a storm so people can get ready and stay safe.

CORE IDEAS

The story. On May 24, 1844, a painter-turned-inventor named Samuel F. B. Morse sat at a small machine in the Supreme Court room of the United States Capitol in Washington. He pressed a key up and down, sending pulses of electricity along a wire strung on poles about 60 km (about 40 mi) to Baltimore. There his partner Alfred Vail read the clicks as dots and dashes and sent the message right back. The words came from the Bible, chosen by a young friend named Annie Ellsworth: "What hath God wrought" (Numbers 23:23). For the first

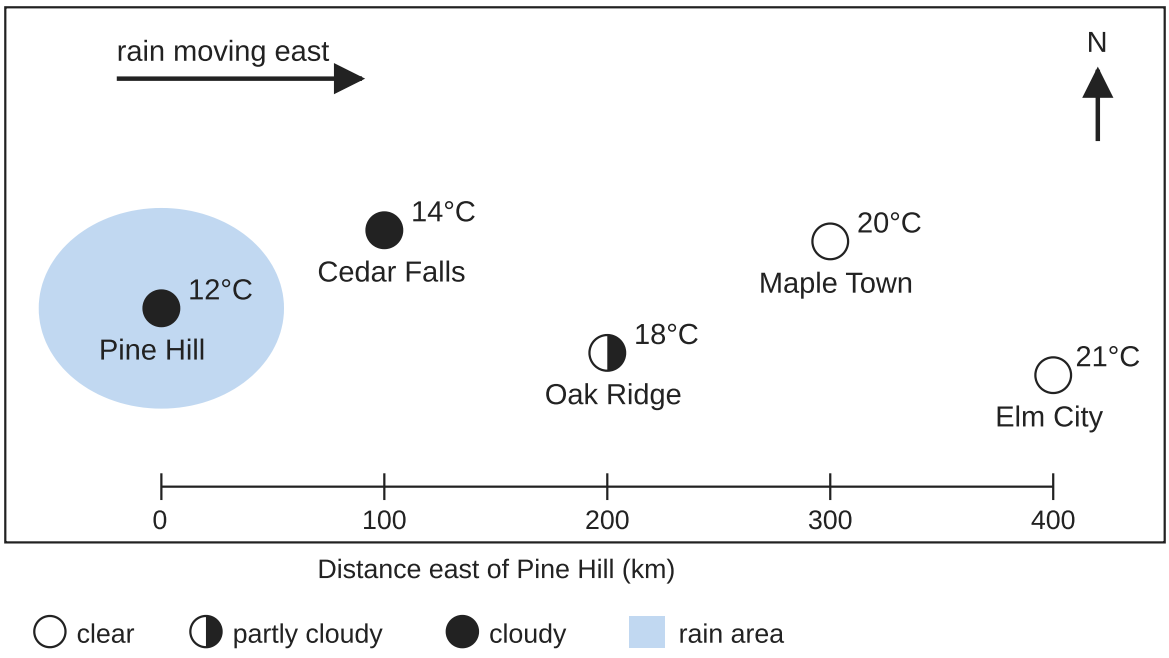
time, news could race between American cities faster than any horse or train. People soon wondered whether the telegraph could race ahead of the weather too.

How they figured it out. Joseph Henry was a scientist whose powerful electromagnets had helped make the telegraph possible. In 1846 he became the first Secretary of the new Smithsonian Institution. He gave weather instruments to volunteer observers and arranged for telegraph lines to carry weather reports to Washington each morning. In the 1850s a large map of the country hung in the Smithsonian building, and each day small colored cards were placed on it to show which towns had fair weather, rain, snow or clouds. Visitors could see the weather of half a continent at a glance. Watching the map day after day, Henry noticed that storms usually marched across the country from west to east, so a storm in the West could be announced in the East before it arrived.

The big idea. A **weather map** is a picture of the weather at many places at the *same moment*. That is why the telegraph mattered so much. A letter about Tuesday's rain in Ohio might reach Washington days later, long after the rain had passed. With the telegraph, reports taken at the same hour in many towns could all reach one office the same day. Each place that reports is a **weather station**. On a simple map, each station gets a small circle: empty for clear skies, half filled for partly cloudy, and filled for cloudy, with the temperature written beside it. Put today's map next to yesterday's and you can watch a storm move, like the pages of a flip book.

Try it and see. Once you can see a storm's path and speed, you can make a forecast with simple arithmetic. If rain is 300 km (about 190 mi) west of your town and moving east at 25 km per hour (about 16 mph), it should arrive in about 300 ÷ 25 = 12 hours. In this lesson you will build your own "telegraph network" by asking friends and relatives in other towns for their weather at the same hour, and you will put their reports on a map, just as Henry's helpers did.

In the world today. On February 9, 1870, President Ulysses S. Grant signed the law that started a national weather service, run at first by the Army's Signal Service. One of its leaders, Cleveland Abbe, had already been sending out daily weather "probabilities" from the Cincinnati Observatory, and people nicknamed him "Old Probabilities." Today's National Weather Service gathers reports from thousands of stations, weather balloons, radar and satellites, and computers help draw the maps. But the idea is the same one Henry used: gather many observations taken at the same time, put them on one map, and watch which way the weather is going. Morse's first message still fits: what hath God wrought!



A simple weather map. Each town is 100 km (about 60 mi) east of the one before it. The rain is moving east.

PICTURE STUDY



The House of Representatives, Samuel F. B. Morse, 1822, probably reworked 1823 · Oil on canvas · National Gallery of Art, Washington, D.C.

Before he invented the telegraph, Samuel Morse was a painter. In 1822 he painted this enormous picture of the House of Representatives in the U.S. Capitol at the start of an evening session, with the lamps being lit. He worked for months, drawing the hall exactly and painting dozens of real congressmen and visitors. Morse hoped people would pay to see it when he took it on tour, but too few came, and the painting lost him money.

Twenty-two years later Morse was back in the Capitol, not with a paintbrush but with a telegraph key. The same careful eye that measured every column in this hall helped him build a machine that changed how the world shared news, including news about the weather.

Look closely

- Find the great chandelier hanging from the dome. What is happening to it?
- Look at the columns. How did Morse make the hall look deep and round on a flat canvas?
- Find the light in the painting. Where does it seem to come from at this evening hour?
- Look at the people. Are they large or small compared with the room? Why might Morse have painted them that way?

Talk about it

1. What skills does a good painter share with a good scientist?
2. Why do you think Morse chose words from the Bible for his first long-distance message?
3. How would your family get news of a storm if there were no telephones, radios or internet?

EXPERIMENT: OUR FAMILY WEATHER NETWORK

Joseph Henry’s map worked because many people reported the weather at the same time. You will do the same thing with a “telegraph network” of friends and relatives, then put their reports on a map for two days in a row.

Question: Does weather in my part of the country move from west to east? **Prediction:** Write what you think the map will show on the second day.

You will need

- A printed outline map of your state or of the United States
- A list of 5 to 8 friends or relatives in different towns, some to the west of you and some to the east
- A phone or computer (a parent sends the messages)
- Colored pencils: blue for rain or snow, and pencil for station circles
- Your own thermometer, read in the shade
- Notebook

Steps

1. With a parent, choose one time for everyone to report, such as 4 p.m. your time. Ask each person to send the same three things at that time: temperature, sky (clear, partly cloudy, or cloudy), and whether it is raining or snowing.
2. Make a table in your notebook with columns: Town, Time, Temperature, Sky, Rain or snow.

3. At the chosen time, read your own thermometer in the shade and look at your sky. Fill in your row, then fill in the others as reports come in.
4. On the map, draw a small circle at each town. Leave it empty for clear, fill half for partly cloudy, fill it all for cloudy. Write the temperature beside it and shade any rainy town blue.
5. The next day, ask for reports at the same time and make a second map.
6. Lay the two maps side by side. Did the rain or clouds move? In which direction?
7. Write two or three sentences answering your question. Was your prediction right?

Tips

- **What we change:** the day (day 1 and day 2). **What we keep the same:** the time of the reports, the questions asked, the symbols and the units (all °C, or all °F with °C beside it). **What we measure:** temperature, sky and rain at each town.
- Reports taken at different times of day cannot be fairly compared, so the same hour matters most.
- If a relative uses a phone weather app instead of looking outside, write that down in your notes column.

Check your work

- Every report on my map was taken at the same time.
- I used the station symbols correctly and wrote every temperature with its unit.
- I compared two days and wrote what direction the weather moved.

FIELD NOTEBOOK

1. Draw a telegraph key, the wire on its poles, and the receiving machine in the next town. Label which way the message travels.
2. Copy Morse’s first message, “What hath God wrought,” and write Numbers 23:23 beneath it.
3. Draw the three station circles (clear, partly cloudy, cloudy) and make up a symbol of your own for fog. Explain why everyone on a network must use the same symbols.

> **From history.** Across the ocean, Captain Robert FitzRoy, who had once commanded the ship HMS *Beagle*, became head of Britain’s new government weather office in 1854. In October 1859 a fierce storm wrecked the steamship *Royal Charter* off the coast of Wales, and more than 400 people were lost. FitzRoy believed many such disasters could be prevented. Using telegraph reports from stations around the coast, he began sending storm warnings to harbors in 1861, and on August 1, 1861, *The Times* of London began printing his daily weather forecasts. FitzRoy chose the word “forecast” on purpose: he explained that these were not prophecies, but careful judgments worked out from measurements.

WORKED EXAMPLES

Example 1. Washington and Baltimore are about 60 km (about 40 mi) apart. A rider on horseback carrying a message travels about 15 km per hour (about 9 mph). How long would the rider take? How long did Morse's telegraph take?

1. Time = distance ÷ speed.
2. 60 km ÷ 15 km per hour = 4 hours.
3. Electricity travels along a wire almost instantly, so once Morse tapped out the letters, they arrived in Baltimore at the same moment. Tapping the short message took only a minute or two.

Answer: The rider would take about 4 hours. The telegraph message arrived almost at once, in the time it took to tap the letters.

Example 2. Look at the weather map. It is 8 a.m. and rain is falling at Pine Hill. The rain is moving east at 25 km per hour (about 16 mph). Maple Town is 300 km (about 190 mi) east of Pine Hill. About when will the rain reach Maple Town?

(Use the map or drawing "Use the distance scale along the bottom of the map." shown earlier in this lesson.)

1. Read the distance on the scale: Maple Town is at 300 km.
2. Time = distance ÷ speed = 300 km ÷ 25 km per hour = 12 hours.
3. 8 a.m. + 12 hours = 8 p.m.

Answer: About 12 hours later, around 8 p.m., if the rain keeps the same speed and direction.

PRACTICE

1. EASY What words did Samuel Morse send from Washington to Baltimore in 1844, and where in the Bible do they come from?
2. EASY Who was the first Secretary of the Smithsonian Institution, the scientist who used telegraph reports to make a daily weather map?
3. EASY What did Henry notice about the direction storms usually traveled across the United States?
4. MEDIUM Use the weather map. (a) Which town is warmest and which is coldest? (b) What is the difference between them? (c) Which towns have clear skies?
   (Use the map or drawing "Read the temperature beside each station circle." shown earlier in this lesson.)
5. MEDIUM Why must all the reports on a weather map be taken at the same time? Answer in two sentences.

6. MEDIUM On the weather map, the rain at Pine Hill moves east at 25 km per hour (about 16 mph). How many hours until it reaches Cedar Falls, 100 km away? How many hours until it reaches Elm City, 400 km away?
7. HARD Five friends in five towns want to compare temperatures on one map. What is the variable they are comparing? Name three things that must be kept the same at every town so the comparison is fair.
8. CHALLENGE In 1861 a storm is 500 km (about 310 mi) from a harbor, moving toward it at 50 km per hour (about 31 mph). (a) How many hours until it arrives? (b) A rider at 15 km per hour (about 9 mph) must carry the warning 120 km (about 75 mi) to the harbor. How many hours of warning would the sailors have left? (c) How many would they have with the telegraph?

COMMON MISTAKES

- Thinking the telegraph made the forecasts. It only carried the reports quickly; people still had to study the map and decide what the weather would do.
- Thinking a weather map shows the weather for the whole day. It is like a snapshot of one moment; an hour later the weather has already moved.
- Thinking weather always comes from the west. It usually does in the middle latitudes, but some storms, such as hurricanes along the Atlantic coast, can come from the south or east.

> **Make it a game · Telegraph Relay.** Make up a simple code with your family: one tap means rain, two taps mean clear, three taps mean cloudy, and a long scrape means snow. Each player is a “town” in a different room. The first town taps its weather on a wall or table, and the next town writes it down and passes it on, adding its own weather. The last town draws all the reports on a quick map. Score a point for each report that arrives correctly. Time the relay and try to beat your record.

> **Scripture.** “Surely there is no enchantment against Jacob, neither is there any divination against Israel: according to this time it shall be said of Jacob and of Israel, What hath God wrought!” (Numbers 23:23, KJV)

Morse’s first message gave glory to God for a new invention. A forecast is not fortune-telling or “divination”; it is honest work with God’s orderly world, using measurements and reports to make a careful judgment.

Practice answers

1. “What hath God wrought,” from Numbers 23:23.
2. Joseph Henry.
3. They usually moved from west to east.
4. (a) Warmest: Elm City, 21 °C (about 70 °F). Coldest: Pine Hill, 12 °C (about 54 °F). (b) 21 − 12 = 9 °C (about 16 °F). (c) Maple Town and Elm City (empty circles).
5. Weather changes during the day, and storms move from place to place. If the reports were taken at different times, the map would mix morning and evening weather and would not

show where the storm really is at one moment.

6. Cedar Falls: 100 ÷ 25 = 4 hours. Elm City: 400 ÷ 25 = 16 hours.
7. The variable is the town (its location). Keep the same: the time of the reading; the kind of thermometer and the units; where the thermometer is placed (in the shade, about 1.5 m, or 5 ft, above the ground, away from buildings and pavement); and the symbols used to record the sky.
8. (a) 500 ÷ 50 = 10 hours. (b) The ride takes 120 ÷ 15 = 8 hours, leaving only 10 − 8 = 2 hours to prepare. (c) Almost the full 10 hours, because the telegraph message arrives nearly at once.

5.3 Fronts: Where Air Masses Meet

OBJECTIVES

- Explain what an air mass and a front are, and name the cold, warm, stationary and occluded fronts and their map symbols.
- Describe the clouds, rain, temperature and wind changes that usually come with a cold front and with a warm front.
- Read a table of hourly weather readings to tell when a front passed and how much the temperature changed.

Warm-up. Open the freezer door (or the refrigerator door) and hold one hand near the top of the opening and the other near the bottom. Which hand feels the cold air spilling out? Close the door after half a minute. Write one sentence: Does cold air move up or down? Why do you think so?

Video. Coming soon. Weather fronts for kids: search NOAA SciJinks, the National Weather Service JetStream school, the UK Met Office, SciShow Kids, Homeschool Pop and Science Max for cold fronts, warm fronts, air masses, front symbols on weather maps and the warm and cold water “front in a tank” demonstration.

KEY TERMS

air mass
A huge body of air, often as wide as several states, that has about the same temperature and moisture all through it.

front
The boundary where two different air masses meet.

cold front
A front where cold air pushes in under warmer air and lifts it quickly. Map symbol: a blue line with triangles.

warm front
A front where warm air slides up and over cooler air. Map symbol: a red line with half circles.

stationary front
A front that is hardly moving. Map symbol: a line of red half circles and blue triangles on opposite sides.

occluded front
A front formed when a fast cold front catches up with a warm front. Map symbol: a purple line with triangles and half circles on the same side.

CORE IDEAS

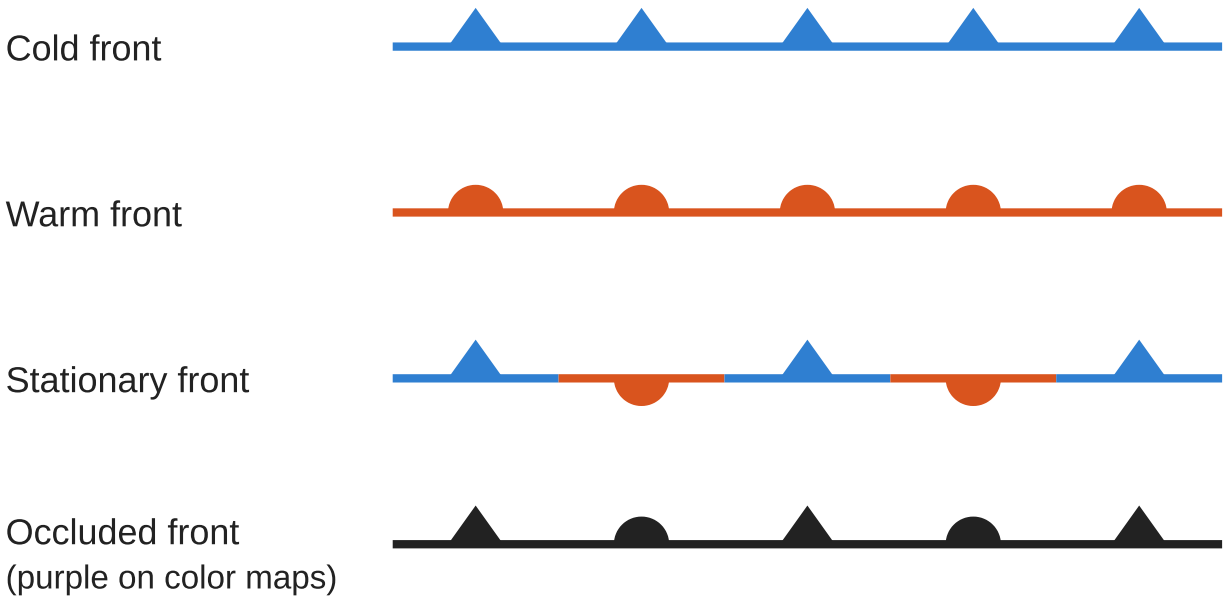
The story. During the First World War, Norway was cut off from most of the weather reports it used to receive from other countries. Its farmers and fishermen still needed forecasts. So in the city of Bergen, a scientist named Vilhelm Bjerknes and a small team of young helpers set up a dense network of weather stations along the Norwegian coast and studied their maps hour by hour. His son Jacob, only about twenty-one years old, noticed that the storms crossing Norway had sharp boundaries between cold air and warm air. In 1919 he described them in a short paper. The team named these boundaries **fronts**, borrowing the word from the battle lines of the war, where two armies met.

The big idea. When air sits over one part of the earth for days, it takes on that place's temperature and moisture. Air over northern Canada in winter becomes cold and dry. Air over the Gulf of Mexico becomes warm and humid. Each of these huge bodies of air is an **air mass**. When two air masses meet, they do not mix easily, just as oil and water do not. The boundary between them is a **front**. A front is not a wall standing straight up; it is a sloping boundary, because cold air is denser (heavier for its size) than warm air and always stays underneath.

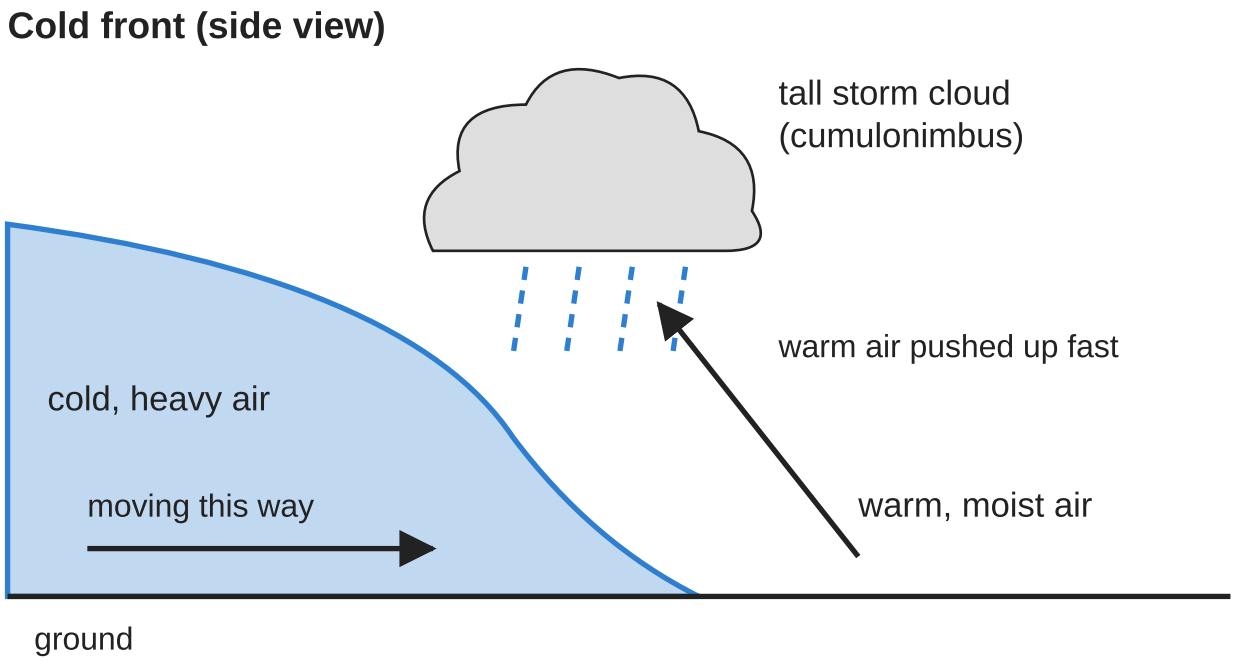
How they figured it out. The Bergen team saw that fronts come in different kinds. At a **cold front**, cold air pushes forward like a snowplow and shoves under the warm air, lifting it up fast and steeply. The rising warm air builds tall cumulonimbus clouds in a narrow band, bringing heavy rain or thunderstorms that usually pass within an hour or two. Behind it the wind shifts, often to the northwest in the United States, the temperature drops, the air feels drier, and the sky clears. On a weather map a cold front is drawn as a **blue line with triangles** pointing the way it is moving.

Try it and see. At a **warm front**, warm air slides gently up and over the cooler air, like a car climbing a long ramp. Because the slope is gentle, the clouds come in order over a day or more: first thin, wispy cirrus high in the sky, then a milky cirrostratus veil that can make a ring around the sun or moon, then gray altostratus, and finally low nimbostratus with long, steady rain or snow. Afterward the air is warmer and more humid. A warm front is drawn as a **red line with half circles**. When neither air mass is winning, the front stalls as a **stationary front**, with red half circles on one side and blue triangles on the other, and it can bring several gray, rainy days. When a fast cold front catches up to a warm front, it makes an **occluded front**, drawn in purple with both shapes on the same side. You will make a cold front of your own with warm and cold water in a clear box.

God's handiwork. Long before anyone drew a front on a map, the book of Job noticed that cold air comes from the north: "Out of the south cometh the whirlwind: and cold out of the north" (Job 37:9). In the Northern Hemisphere, cold air masses really do flow down from the north, and warm ones come up from the south. The meeting of these great rivers of air waters the fields with rain and snow. The Bergen scientists did not invent fronts; they discovered something God had set in motion and gave it a name, so that farmers, fishermen and families could prepare for the weather wisely.



Front symbols on a weather map. The triangles and half circles point the way the front is moving.



At a cold front, cold air wedges under warm air and lifts it fast, building tall storm clouds.

PICTURE STUDY



Approaching Thunder Storm, Martin Johnson Heade, 1859 · Oil on canvas · The Metropolitan Museum of Art, New York

Martin Johnson Heade was an American painter who loved the strange light of the moments just before and after a storm. In this painting, a bay on the New England coast lies perfectly still while an enormous dark storm cloud rolls in overhead. Nothing is moving yet, but everything in the picture seems to be waiting.

The calm water and sudden darkness are just what people often see right before a cold front's line of thunderstorms arrives: the air goes quiet, the sky turns heavy and dark, and then the wind and rain come all at once.

Look closely

- Find the darkest part of the sky and the lightest part. Where is the storm coming from?
- Look at the water. Is it rough or calm? What will happen to it when the storm arrives?
- Look for the people and boats. What might they be thinking as the sky grows dark?
- Find the strip of light near the horizon. What might that tell you about the weather behind the storm?

Talk about it

1. What kind of front could bring a sudden, dark storm like this? Why?
2. Have you ever noticed the air go still and quiet just before a thunderstorm? Describe it.
3. Why do you think Heade chose to paint the moment *before* the storm rather than the storm itself?

> **Safety first.** Use warm tap water only, never boiling water or water heated on the stove. Food coloring can stain clothes and counters, so cover the table with a towel. Wipe up spills at once so no one slips.

EXPERIMENT: A FRONT IN A BOX

Water behaves much like air: cold water is denser than warm water, just as cold air is denser than warm air. You will build a model of a cold front in a clear box and time how fast the cold "air mass" moves.

Question: Does a bigger temperature difference make the cold water slide under the warm water faster? **Prediction:** Write yours before you start.

You will need

- A clear plastic storage box or glass loaf pan, about 30 cm (12 in) long
- A piece of stiff cardboard wrapped in plastic wrap, cut to fit snugly across the middle of the box as a divider
- Two pitchers or large measuring cups
- Ice cubes and cold water
- Warm tap water
- Blue and red food coloring
- A kitchen thermometer
- A stopwatch or phone timer
- Notebook and pencil

Steps

1. Make a table with columns: Trial, Cold side temperature (°C), Warm side temperature (°C), Difference (°C), Seconds for blue to reach the far end, What I saw.
2. Trial 1: Fill one pitcher with room-temperature water and red coloring, and the other with water chilled by ice (strain the ice out) and blue coloring. Measure and record each temperature.
3. Hold the divider in the middle of the box. Pour the same amount of blue water into one half and red water into the other half at the same time, so the water stays level on both sides.
4. Wait 10 seconds for the water to settle. Lift the divider straight up in one smooth motion and start the timer.
5. Watch from the side. Stop the timer when the blue water reaches the far end of the box along the bottom. Record the time and draw what you saw.
6. Empty and dry the box. Trial 2: repeat with ice-cold blue water and warm tap water colored red. Record both temperatures and the time.
7. Compare the two trials. Which side went under, and which went over? Which trial was faster? Was your prediction right?

Tips

- **What we change:** the temperature difference between the two sides. **What we keep the same:** the box, the amount of water on each side, the amount of food coloring and the way you lift the divider. **What we measure:** the seconds for the blue water to reach the far end.
- Do each trial twice if you can and use the average time. Real scientists repeat their tests.
- Look closely where the colors meet. The sloping edge you see is your model front.

Check your work

- I changed only one thing between my trials.
- I recorded the temperatures and the times for every trial.
- I can explain why the cold water slid under the warm water and how this is like a cold front.

FIELD NOTEBOOK

1. Draw the four front symbols from memory, color them, and label each one.
2. Draw a side view of a warm front, with warm air sliding up over cold air. Add the four cloud types in order: cirrus, cirrostratus, altostratus, nimbostratus.
3. Look at a weather map in a newspaper or on the National Weather Service website. Copy one front you find, write what kind it is, and tell which way it is moving.

> **From history.** Vilhelm Bjerknes, the leader of the Bergen team, had an even bolder idea years earlier. In 1904 he wrote that weather follows the same laws of physics as everything else, so it should be possible to calculate tomorrow’s weather from careful measurements of today’s air: its pressure, temperature, moisture and wind. In his day the arithmetic would have taken far too long to finish before the weather arrived. Today’s forecast computers do exactly the kind of calculating Bjerknes imagined, many millions of steps every second.

WORKED EXAMPLES

Example 1. A family recorded the temperature every hour one summer afternoon.
12 p.m.: 24 °C (75 °F)
1 p.m.: 25 °C (77 °F)
2 p.m.: 25 °C (77 °F)
3 p.m.: 18 °C (64 °F)
4 p.m.: 16 °C (61 °F)
5 p.m.: 15 °C (59 °F)
Between which two readings did a front pass? What kind of front was it? How much did the temperature drop from the warmest reading to the last one?

1. Look for the biggest jump: from 25 °C at 2 p.m. to 18 °C at 3 p.m., a drop of 7 °C in one hour.
2. A sudden drop in temperature is a sign that cold air has arrived, so this was a cold front.
3. Warmest reading: 25 °C. Last reading: 15 °C. 25 − 15 = 10 °C.
4. In Fahrenheit: 77 − 59 = 18 °F.

Answer: The front passed between 2 p.m. and 3 p.m. It was a cold front. The temperature dropped 10 °C (18 °F) from 25 °C to 15 °C.

Example 2. On Monday at 9 a.m. you see thin cirrus clouds spreading across the sky from the west. The weather service says a warm front is 600 km (about 370 mi) away, moving toward you at 20 km per hour (about 12 mph). When should the warm front arrive?

1. Time = distance ÷ speed = 600 km ÷ 20 km per hour = 30 hours.
2. 30 hours = 24 hours + 6 hours.
3. Monday 9 a.m. + 24 hours = Tuesday 9 a.m. Then + 6 hours = Tuesday 3 p.m.

Answer: About Tuesday at 3 p.m. The cirrus clouds were the first warning, more than a day ahead.

PRACTICE

1. EASY What is an air mass?
2. EASY How is a cold front drawn on a weather map? How is a warm front drawn?
3. EASY Which kind of front usually brings long, steady rain, and which brings short, heavy storms?
4. MEDIUM Read this table of weather readings.
   3 p.m.: 27 °C (81 °F), wind from the south
   4 p.m.: 27 °C (81 °F), wind from the southwest

5 p.m.: 20 °C (68 °F), wind from the northwest
6 p.m.: 18 °C (64 °F), wind from the northwest
(a) When did the front pass? (b) How much did the temperature fall from 3 p.m. to 6 p.m.? (c) What kind of front was it? Give two clues.

5. MEDIUM Put these clouds in the order you would see them as a warm front comes near: nimbostratus, cirrus, altostratus.
6. MEDIUM Ben wants to test whether the temperature of the cold water changes how fast it slides under warm water in his “front in a box.” What is his variable? Name three things he must keep the same. What should he measure?
7. HARD Why does cold air always end up underneath warm air at a front?
8. CHALLENGE Explain why a cold front usually brings a narrow band of tall storm clouds, while a warm front brings wide layers of clouds and gentle rain that lasts longer.

COMMON MISTAKES

- Thinking a front is a straight-up wall at the ground. A front is a sloping boundary that leans over the cold air, reaching high into the sky.
- Thinking warm air pushes under cold air at a warm front. Warm air is lighter, so it always rides up and over the cold air.
- Thinking the triangles or half circles point back toward where the front came from. They point in the direction the front is moving.

> **Make it a game · Which Front Am I?.** A parent reads a clue card, such as “The temperature fell 8 degrees and the wind turned northwest,” “Cirrus clouds, then a ring around the moon, then a whole day of drizzle,” or “Three days of gray, rainy weather that would not move.” You name the front and draw its symbol on a whiteboard as fast as you can. Score 1 point for the right front and 1 more for the right symbol. First to 10 wins.

> **Scripture.** “Out of the south cometh the whirlwind: and cold out of the north.” (Job 37:9, KJV)

Job 37 is a whole chapter about God’s power in the weather. This verse matches what we see on weather maps: in the Northern Hemisphere, cold air masses sweep down from the north, and warm, moist air flows up from the south.

Practice answers

1. A huge body of air that has about the same temperature and moisture all through it.
2. Cold front: a blue line with triangles. Warm front: a red line with half circles. The shapes point the way the front is moving.
3. A warm front usually brings long, steady rain. A cold front usually brings short, heavy rain or thunderstorms.
4. (a) Between 4 p.m. and 5 p.m. (b) 27 − 18 = 9 °C (about 17 °F). (c) A cold front. Clues: the temperature dropped quickly, and the wind shifted from the south to the northwest.
5. Cirrus first (high and thin), then altostratus (a gray middle layer), then nimbostratus (low, with steady rain).

6. The variable is the temperature of the cold water (or the temperature difference). Keep the same: the box, the amount of water on each side, the temperature of the warm water, the amount of food coloring, and how the divider is lifted. Measure the time in seconds for the cold water to reach the far end.
7. Cold air is denser than warm air; the same amount of space holds more air when it is cold, so it is heavier and sinks below the lighter warm air.
8. At a cold front the boundary is steep, so the warm air is pushed up fast in a narrow strip, building tall cumulonimbus clouds and short, heavy storms. At a warm front the boundary slopes gently, so the warm air rises slowly over a very wide area, making flat layers of cloud and lighter, steady rain that can last many hours.

5.4 Make a 3-Day Forecast and Check It

OBJECTIVES

- Gather observations of temperature, air pressure, clouds and wind and use them to write a 3-day forecast.
- Check a forecast against what really happened and score it with simple arithmetic.
- Explain what “a 40 percent chance of rain” means and why forecasts for later days are less certain.

Warm-up. Step outside or look out a window for two minutes. Write down what you see: the sky, the clouds, which way the wind is blowing the leaves or a flag, and whether it feels warm or cool. Now write a one-sentence forecast for tomorrow on a slip of paper, fold it, and seal it in an envelope with today’s date. Open it tomorrow and see how you did.

Video. Coming soon. How weather forecasts are made and checked: search NOAA SciJinks, the National Weather Service, NASA Earth Observatory, the UK Met Office, SciShow Kids and Homeschool Pop for how forecasters use observations, what “chance of rain” means, weather balloons and satellites, and the D-Day weather forecast of June 1944.

KEY TERMS

forecast
A careful, written judgment about what the weather will do, made before it happens.

persistence forecast
The simplest forecast: “tomorrow will be like today.” A good forecaster tries to do better than it.

chance of rain
How likely rain is at one spot, given as a percent. A 40 percent chance means about 4 chances in 10.

error
How far a forecast missed. For temperature, it is the difference between the forecast and the measured temperature.

upstream
The direction the weather is coming from. In the middle latitudes, that is usually the west.

CORE IDEAS

The story. In early June 1944, at Southwick House near Portsmouth on the south coast of England, a Scottish weather scientist named James Stagg faced the hardest forecast of his life. He was the chief weather adviser to General Dwight D. Eisenhower, who was ready to

send a huge army across the English Channel to free France. The landing needed seas calm enough for small boats, clouds high enough for airplanes, and the right tides and moonlight. It was planned for June 5, but a storm was coming. On June 4 Stagg advised waiting, and Eisenhower delayed the landing. Then Stagg's team saw something in the reports: a short break in the storm, expected for June 6. Eisenhower trusted the forecast and gave the order. The landings, now called D-Day, went ahead on June 6, 1944.

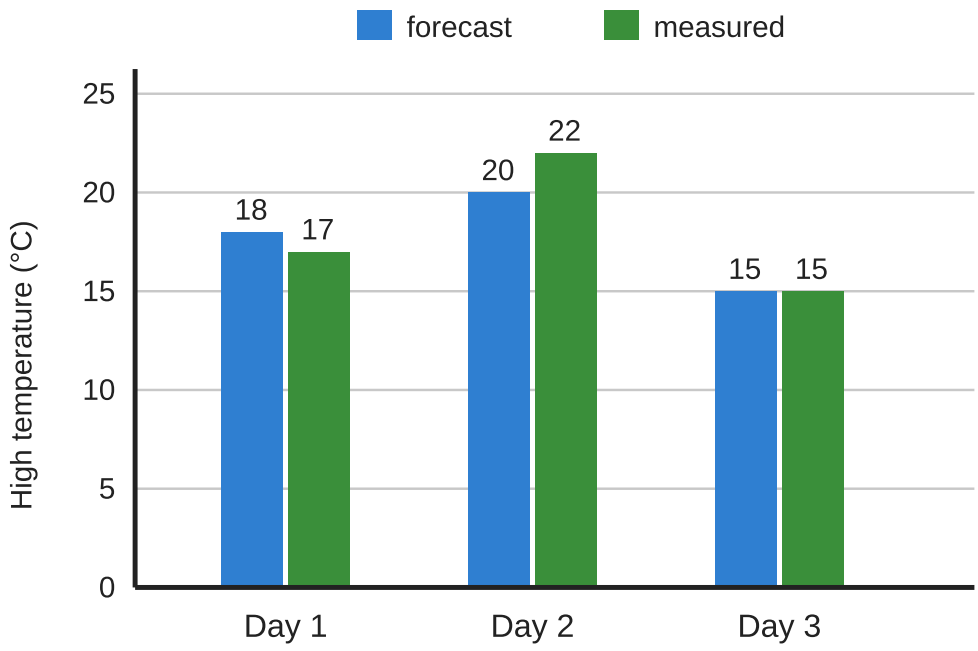
How they figured it out. Stagg's teams read reports from weather ships, airplanes and stations all around the North Atlantic. Weather in Europe usually comes in from the west, off the ocean, so reports from the west were the most valuable of all. One came from a lighthouse at Blacksod Point on the west coast of Ireland, where the keepers recorded the barometer falling as the storm drew near. The forecasters on the other side of the war had far fewer reports from the open Atlantic, and they did not expect a break in the weather. Good observations from **upstream**, the direction the weather comes from, made the difference.

The big idea. A forecast is built from **observations** plus **patterns**, and you already know the main ones. A falling barometer usually means stormy or unsettled weather is coming; a rising barometer usually means fairer weather. Cirrus clouds that thicken into a gray altostratus sheet warn of a warm front. A sudden drop in temperature and a wind shift to the northwest mean a cold front has passed. A red evening sky hints at fair weather, and whatever is happening to the west of you today may reach you tomorrow. The simplest forecast of all is a **persistence forecast**: "tomorrow will be like today." It is often right for a day or so, and a good forecaster tries to beat it.

In the world today. Forecasters also tell how sure they are. "A 40 percent chance of rain" means there are about 4 chances in 10 that rain will fall at any one spot in the forecast area. Forecasts for tomorrow are right more often than forecasts for next week, because small mistakes in today's measurements grow larger each day, and the weather that will arrive later is still far away. NOAA's SciJinks website says a 5-day forecast is right about 90 percent of the time, a 7-day forecast about 80 percent of the time, and a 10-day forecast only about half the time.

Try it and see. In this lesson you will become a forecaster. You will gather your own observations, write a forecast for the next three days, and then check it day by day. Checking matters as much as forecasting. A scientist writes the forecast *before* the weather happens, compares it honestly with what really happened, and keeps score, even when the score is disappointing. Your first day will probably be your best. If day 3 is harder, you will have discovered for yourself why forecasters say "chance."

God's handiwork. The apostle James wrote, "Ye know not what shall be on the morrow" (James 4:14). Only God knows the future for certain. A forecast is a humble, careful best guess, made with the orderly world and the good minds He has given us. Used wisely, it helps families, farmers, sailors and pilots make good plans, while remembering that every tomorrow is in His hands.



Checking a 3-day forecast: forecast highs (blue) and measured highs (green).

PICTURE STUDY



Sudden Shower over Shin-Ōhashi Bridge and Atake, Utagawa Hiroshige, 1857 · Color woodblock print, from the series *One Hundred Famous Views of Edo* · Library of Congress, Washington, D.C. (one of many surviving impressions)

Utagawa Hiroshige was a Japanese artist who made woodblock prints of the roads, rivers and weather of his country. To make a print, carvers cut each color into a separate block of wood, and printers pressed the blocks onto paper one after another. In this print, a sudden

summer shower has caught people crossing a great bridge in the city of Edo, now called Tokyo.

Hiroshige drew the rain as hundreds of fine straight lines, some darker than others, so the shower seems to sweep across the paper. The Dutch painter Vincent van Gogh admired this print so much that in 1887 he painted his own copy of it.

Look closely

- Find the rain. How did Hiroshige show it? Are all the lines the same darkness?
- Look at the people on the bridge. How can you tell the shower surprised them?
- Find the raft on the river. Is the raftsman hurrying too?
- Look at the sky at the top of the print. What kind of cloud might bring a sudden, heavy shower like this?

Talk about it

1. If you had been forecasting for these people that morning, what clues might have warned you about the shower?
2. Why are short, sudden showers harder to forecast than a long, steady rain from a warm front?
3. Has a surprise shower ever caught you outdoors? What did you do?

> **Safety first.** Make your observations from a safe place. If you hear thunder, go indoors right away and stay in until 30 minutes after the last thunder. Never look straight at the sun. Handle glass thermometers and jars carefully.

EXPERIMENT: MY 3-DAY FORECAST CHALLENGE

You will make a real 3-day forecast from your own observations, then check it each day and compare your score with two other forecasts: the persistence forecast (“tomorrow will be like today”) and the official National Weather Service forecast.

Question: Can my forecast beat the persistence forecast? **Prediction:** Write which of the three forecasts you think will score best.

You will need

- An outdoor thermometer hung in the shade, about 1.5 m (5 ft) above the ground
- Your homemade barometer from Lesson 2.2, or a household barometer
- A rain gauge: a straight-sided clear jar with a ruler taped to the side, set in an open spot
- Your cloud chart from Unit 3
- A compass, or knowledge of which way is north
- Notebook, pencil and an envelope
- The official forecast for your town from weather.gov (a parent can print it)

Steps

1. **Day 0, morning:** Read and record your barometer.
2. **Day 0, 3 p.m.:** Record the temperature, the barometer again (rising, falling or steady since morning?), the cloud types, the wind direction, and whether it has rained. Ask a relative to the west, or look at a weather map, to see what weather is upstream.
3. Write your forecast for Days 1, 2 and 3: the 3 p.m. temperature, the sky (clear, partly cloudy, cloudy) and rain (yes or no). Under it, write one reason for each day. Seal it in the envelope.
4. On the same page, write the persistence forecast (Day 0's weather copied for all three days) and copy the official forecast.
5. **Days 1, 2 and 3, at 3 p.m.:** Record the actual temperature, sky and rain, the same way and in the same place as on Day 0.
6. **Score:** For each forecast and each day, find the temperature error (the difference between forecast and actual). Add the errors and divide by 3 for the average error. Then count how many rain forecasts (yes or no) were right out of 3.
7. Make a bar graph of your forecast highs and the actual highs, like the one in this lesson. Write which forecast won and what you would do differently next time.

Tips

- **What we change:** the forecast method (mine, persistence, official). **What we keep the same:** the days, the thermometer and its shady spot, the time of reading (3 p.m., near the warmest part of the day) and the scoring rule. **What we measure:** temperature error and rain forecasts right.
- Never change your forecast after you have sealed it. Honest records are the heart of science.
- Three days is a small test. If you enjoy it, keep forecasting for two weeks and see whose average error is smallest.

Check your work

- I wrote and sealed my forecast before the weather happened.
- I measured at the same time and place every day.
- I found the average temperature error and the rain score for all three forecasts.

FIELD NOTEBOOK

1. Make a forecast card for tomorrow like a television weather forecaster: draw the sky, write the temperature with °C and °F, and give a chance of rain as a percent.
2. Draw your weather station: thermometer in the shade, barometer, rain gauge and wind direction. Label each with what it measures.
3. Draw a small map of the English Channel area with England to the north and France to the south, and an arrow showing weather coming in from the Atlantic Ocean in the west. Write one sentence about James Stagg's forecast.

From history. On April 1, 1960, NASA launched TIROS-1, the first successful weather satellite. Its small television cameras sent back the first pictures of the earth's clouds taken from space, showing whole storm systems at once, far bigger than any map drawn from ground stations alone. Today weather satellites watch the clouds day and night, and forecasters still do what Joseph Henry and James Stagg did: gather observations, look upstream, and check every forecast against what really happened.

WORKED EXAMPLES

Example 1. Look at the bar graph. Lucy forecast highs of 18 °C, 20 °C and 15 °C. The measured highs were 17 °C, 22 °C and 15 °C. Find her error for each day and her average error. Which day was her best?

(Use the map or drawing "Compare each pair of bars to find the error." shown earlier in this lesson.)

1. Day 1: 18 − 17 = 1 °C error (forecast 1 degree too warm).
2. Day 2: 22 − 20 = 2 °C error (forecast 2 degrees too cool).
3. Day 3: 15 − 15 = 0 °C error.
4. Total error: 1 + 2 + 0 = 3 °C. Average: 3 ÷ 3 = 1 °C.
5. The smallest error was on Day 3.

Answer: Errors: 1 °C, 2 °C and 0 °C. Average error: 1 °C (about 2 °F). Her best day was Day 3, a perfect forecast.

Example 2. A forecaster said "30 percent chance of rain" on 10 different days. Rain fell on 3 of those days and stayed dry on 7. Was the forecaster wrong on the 7 dry days?

1. A 30 percent chance means about 3 chances in 10.
2. Out of 10 such days, we would expect rain on about 3 of them.
3. Rain fell on 3 of the 10 days, exactly what the forecast said to expect.

Answer: No. A 30 percent chance means rain on about 3 out of 10 such days, and that is just what happened. The forecaster was right on the whole set of days.

PRACTICE

1. EASY Your barometer has been falling all afternoon. What kind of weather does that usually mean is coming?
2. EASY What is a persistence forecast?
3. EASY What does "a 60 percent chance of rain" mean?
4. MEDIUM Read this table of forecast and measured highs.
   Monday: forecast 20 °C, actual 21 °C
   Tuesday: forecast 22 °C, actual 22 °C

Wednesday: forecast 19 °C, actual 16 °C
Thursday: forecast 18 °C, actual 19 °C
Friday: forecast 21 °C, actual 21 °C
(a) Find the error for each day. (b) Which day had the biggest miss? (c) What was the average error?

5. MEDIUM Why is a forecast for 3 days from now less certain than a forecast for tomorrow? Give two reasons.
6. MEDIUM Mia wants to find out which works better: her own forecasts, the persistence forecast, or the official forecast. What is her variable? Name three things she must keep the same. What will she measure to decide the winner?
7. HARD Why were weather reports from Ireland and the Atlantic Ocean so important for James Stagg's D-Day forecast?
8. CHALLENGE Two forecasts were checked for 3 days.
Forecast A: rain right 3 out of 3; temperature errors 4, 5 and 3 °C.
Forecast B: rain right 2 out of 3; temperature errors 1, 1 and 2 °C.
Find each average temperature error. Which forecast would you rather use for planning a picnic? Explain.

COMMON MISTAKES

- Thinking "30 percent chance of rain" means it will rain for 30 percent of the day or over 30 percent of the town. It means about 3 chances in 10 of rain at any one spot.
- Thinking a forecast that missed once was useless. Forecasts are judged by their score over many days, not by one day.
- Reading the thermometer in the sun or next to a wall. Air temperature must be measured in the shade, away from buildings and pavement, or the reading will be too high.

> **Make it a game · Family Forecast Cup.** Each evening, every family member writes a forecast for tomorrow's 3 p.m. temperature and whether it will rain. One extra "player" is Persistence, which always guesses today's weather. The next day, the closest temperature earns 2 points and every correct rain forecast earns 1 point. Keep a scoreboard for a week. Can anyone beat Persistence?

> **Scripture.** "Whereas ye know not what shall be on the morrow. For what is your life? It is even a vapour, that appeareth for a little time, and then vanisheth away." (James 4:14, KJV)

James reminds us that only God knows tomorrow for certain. Our life is like the water vapor we have studied: here for a little while. A wise forecaster works carefully, speaks humbly, and trusts God with the future.

Practice answers

1. Stormy or unsettled weather, often clouds and rain.

2. A forecast that says tomorrow’s weather will be the same as today’s.
3. There are about 6 chances in 10 that rain will fall at any one spot in the forecast area.
4. (a) Monday 1, Tuesday 0, Wednesday 3, Thursday 1, Friday 0 (all in °C). (b) Wednesday, off by 3 °C (about 5 °F); perhaps a cold front came through. (c) Total 1 + 0 + 3 + 1 + 0 = 5; 5 ÷ 5 = 1 °C average error.
5. Small errors in today’s measurements grow bigger each day, and the weather that will arrive in 3 days is still far away, where there may be fewer observations. Things like new storms can also form in between.
6. The variable is the forecast method. Keep the same: the days being forecast, the thermometer and where it hangs, the time of reading, and the scoring rule. Measure each method’s temperature errors (and average error) and how many rain forecasts were right.
7. Weather in Europe usually moves from west to east, off the Atlantic. Reports from the west were upstream, so they showed the weather that was coming toward the English Channel next.
8. A: (4 + 5 + 3) ÷ 3 = 12 ÷ 3 = 4 °C. B: (1 + 1 + 2) ÷ 3 = 4 ÷ 3, about 1.3 °C. A was better for rain and B was much better for temperature. For a picnic, rain matters most, so many people would choose A; a good answer explains which part matters most for the plan.

Unit 5 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) In Matthew 16:2–3, what did Jesus say people expected after a red sky in the evening, and after a red, lowring sky in the morning?
2. (5 pts) Why is the sky red and orange at sunset?
3. (5 pts) Weather in your town usually moves from west to east. Explain why a red sky in the morning can be a warning.
4. (5 pts) What message did Samuel Morse send by telegraph in 1844, and why did the telegraph make weather maps possible?
5. (5 pts) Rain is 240 km (about 150 mi) west of your town, moving east at 30 km per hour (about 19 mph). How many hours until it arrives? If it is now 10 a.m., what time will that be?
6. (5 pts) On a weather map, what do an empty station circle, a half-filled circle and a filled circle mean? Why must all the reports be taken at the same time?
7. (5 pts) Describe the map symbols for a cold front and a warm front. What does each usually bring?
8. (5 pts) Hourly readings: 1 p.m. 26 °C, 2 p.m. 26 °C, 3 p.m. 19 °C, 4 p.m. 17 °C. The wind turned from south to northwest at 3 p.m. What happened, and how much did the temperature fall from 2 p.m. to 4 p.m.?
9. (5 pts) What does “a 40 percent chance of rain” mean? What is a persistence forecast?
10. (5 pts) A 3-day forecast gave highs of 12 °C, 15 °C and 18 °C. The measured highs were 14 °C, 15 °C and 17 °C. Find the error for each day and the average error.

Unit project: my forecaster’s notebook

Put together a forecaster’s notebook that shows everything you did as a weather scientist in this unit. Include your red-sky record (at least 10 evenings or mornings with next-day weather and the fraction of times the saying worked), your two-day family weather map, your “front in a box” data table and drawing, and your 3-day forecast with its sealed-envelope forecast, daily records, scorecard and bar graph comparing your forecast with the persistence and official forecasts.

Finish with a one-page weather report for your town, as if you were Joseph Henry or James Stagg: describe today’s observations, name any front on the weather map, give a forecast for tomorrow with a chance of rain, and explain the reasons for your forecast.

- **Observations**: Records are complete, dated and timed, taken the same way each day, with units in °C (and °F where used).
- **Accuracy**: Fractions, errors and averages are correctly worked; front symbols and station symbols are drawn correctly.

- **Explanation**: The weather report and notes explain red skies, west-to-east weather, fronts and chance of rain in clear, correct sentences.
- **Honesty and care**: Forecasts were written before the weather happened and never changed; the notebook is neat, labeled and easy to follow.

Answer key

1. Red at evening: “It will be fair weather.” Red and lowring in the morning: “It will be foul weather to day.”
2. At sunset, sunlight travels a long, slanting path through much more air. Air scatters blue light more than red, so most of the blue is scattered away and mostly red and orange light reaches us.
3. In the morning the sun is in the east. If it lights clouds red, those clouds are usually in the west, the direction weather comes from, so they may be moving toward you and bringing rain.
4. “What hath God wrought” (Numbers 23:23). The telegraph carried weather reports from many towns almost instantly, so observations taken at the same time could be put on one map before the weather changed.
5. 240 ÷ 30 = 8 hours. 10 a.m. + 8 hours = 6 p.m.
6. Empty: clear. Half filled: partly cloudy. Filled: cloudy. The reports must be taken at the same time because weather moves and changes; reports from different times would not show where the weather really is at one moment.
7. Cold front: a blue line with triangles; it brings short, heavy rain or thunderstorms, then cooler, drier air and a wind shift. Warm front: a red line with half circles; it brings layers of cloud, long steady rain or snow, then warmer, more humid air.
8. A cold front passed between 2 p.m. and 3 p.m. The temperature fell 26 − 17 = 9 °C (about 16 °F).
9. About 4 chances in 10 that rain will fall at any one spot in the forecast area. A persistence forecast says tomorrow’s weather will be the same as today’s.
10. Errors: 2 °C, 0 °C and 1 °C. Total 3 °C; average 3 ÷ 3 = 1 °C.

UNIT 6

Rivers and Floods

Rivers are some of God's greatest gifts to people. They water farms, carry boats, turn mills and give cities their drinking water. But when more water comes than a river channel can carry, the river spills out over the land in a **flood**. In this unit you will learn why floods happen, how a river and all the land around it work together as a **watershed**, and how engineers and builders protect towns and homes with dams, levees, floodways and wise building.

You will begin in a Pennsylvania valley on May 31, 1889, when the South Fork Dam broke and the Johnstown Flood swept through a steel town. You will stand on the Mississippi levees in the great flood of 1927, look up at the curved wall of Hoover Dam, ride the Colorado River with one-armed explorer John Wesley Powell, and visit the Illinois town that moved itself to higher ground. Along the way you will build a sand dam, carve levees in a pan, make a crumpled-paper watershed and design a flood-proof model house, measuring and recording like a real engineer.

BEFORE YOU BEGIN

- Knows the parts of the water cycle: evaporation, condensation, precipitation and runoff (Unit 1)
- Can read a rain gauge or ruler in centimeters and inches
- Can multiply and divide whole numbers and find the average of three numbers
- Knows what a fair test is: change one thing and keep the rest the same

MASTERY CHECKLIST

- I can tell the story of the Johnstown Flood and explain why the South Fork Dam failed.
- I can explain how levees, dams and floodways help control floods, and name a weakness of each.
- I can define a watershed, a divide and a tributary, and trace a raindrop's path to the sea.
- I can explain why pavement causes more runoff than forest soil.
- I can explain what a 100-year flood means and name four ways to protect a house from floods.
- I can plan a fair test, record data in a table, find an average and make a bar graph.

OPTIONAL BOOKS AND RESOURCES

- **USGS Water Science School** (https://www.usgs.gov/special-topics/water-science-school): Free. Clear articles, diagrams and pictures from the U.S. Geological Survey on watersheds, runoff, floods and rivers. A parent can read sections aloud.
- **Johnstown Flood National Memorial (National Park Service)** (https://www.nps.gov/jofl/): Free. The park's website tells the story of the 1889 flood

with photographs and maps of the South Fork Dam. If you live near western Pennsylvania, the park is a wonderful field trip (Lesson 6.1).

- **NOAA SciJinks** (https://scijinks.gov/): Free. Kid-friendly weather and water science from NOAA and NASA, including how floods form and how forecasters warn people.

6.1 The Johnstown Flood (1889) ★

OBJECTIVES

- Tell the true story of the Johnstown Flood of May 31, 1889, and explain why the South Fork Dam failed.
- Explain how heavy rain, a narrow valley and a weak dam worked together to turn a river into a deadly flood.
- Calculate how fast the flood wave traveled and name rules that keep people safe when floods come.

Warm-up. Over a sink, fill a zip-top sandwich bag half full of water and hold it up. Ask a parent to poke one tiny pinhole near the bottom with a pin. Watch the thin stream. Now have them make the hole as big as a pencil. What happens to the water? A slow leak and a sudden break are very different. Keep that picture in your mind for today's story.

Video. Coming soon. Johnstown Flood 1889 and the South Fork Dam for kids: search the National Park Service (Johnstown Flood National Memorial), history channels for young students, and simple dam-break demonstration videos from science educators such as Science Max or USGS.

KEY TERMS

flood
Water covering land that is usually dry.

flash flood
A flood that rises very fast, within minutes or a few hours, often after very heavy rain or a dam break.

dam
A wall built across a river or stream to hold back water.

reservoir
A lake made by a dam, where water is stored.

spillway
A channel that lets extra water flow safely around or over a dam so the water does not pour over the top of the dam itself.

CORE IDEAS

The story. On the afternoon of May 31, 1889, the busy steel town of Johnstown, Pennsylvania, sat in a narrow valley where two streams, the Little Conemaugh River and Stony Creek, meet. About 23 kilometers (14 miles) up the valley, high in the hills, an old earthen dam held back a lake called Lake Conemaugh. Rain had poured down all night, the heaviest rain people in that area had ever seen: about 15 to 25 centimeters (6 to 10 inches)

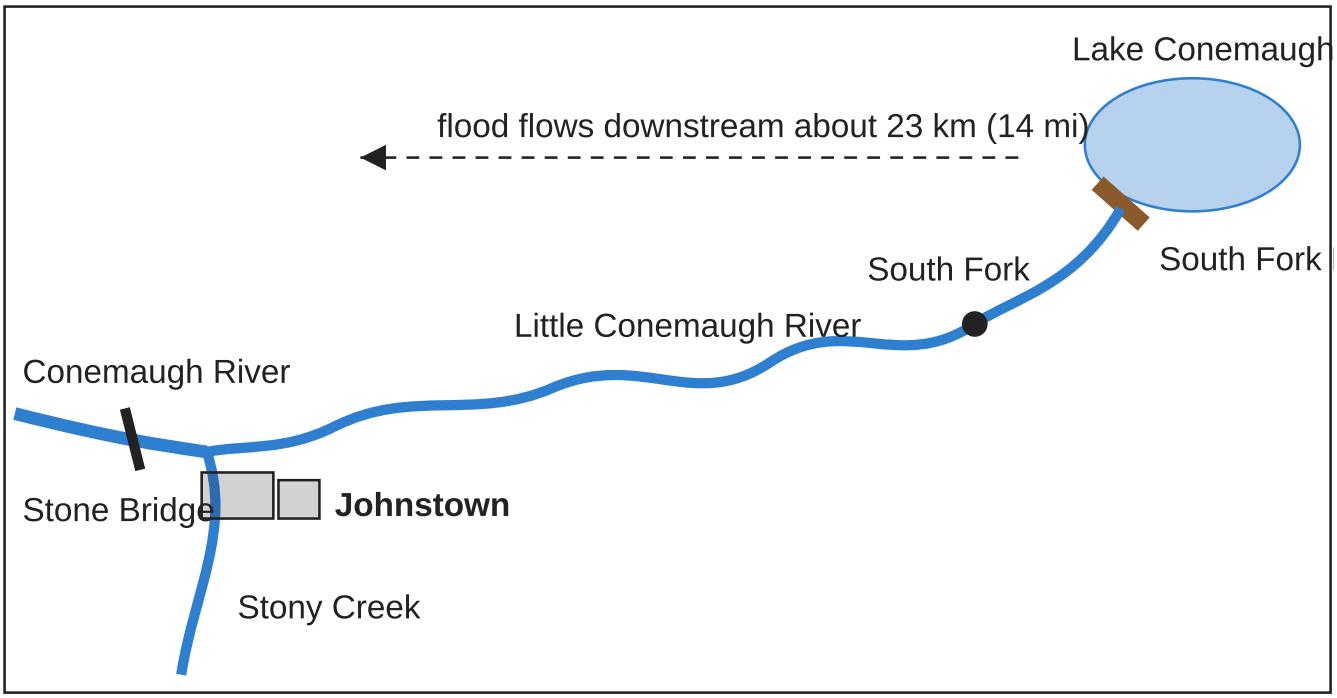
in one day. The streets of Johnstown were already under water. At about 3:10 in the afternoon, the South Fork Dam gave way. The whole lake, about 20 million tons of water, rushed down the valley. Less than an hour later, a wall of water and wreckage, often described as 10 to 12 meters (35 to 40 feet) high, struck Johnstown. In about ten minutes most of the town was swept away, and 2,209 people died.

How they figured it out. After the flood, engineers studied the broken dam. It was a huge bank of earth and rock, about 22 meters (72 feet) high, built by the state of Pennsylvania to store water for a canal. Later the South Fork Fishing and Hunting Club, a group of wealthy men from Pittsburgh, bought it for summer boating and fishing. The engineers found several problems. The big pipes at the bottom, which could have let water out to lower the lake, had been taken out years before and never replaced. The top of the dam had been lowered a little to make a road wide enough for carriages, so there was less room above the water. Screens had been put across the spillway to keep the fish from escaping, and on the flood day they clogged with branches. The middle of the dam had sagged and been patched with dirt. When the lake rose faster than the spillway could carry water away, water poured over the top, and an earthen dam that is overtopped washes away from the top down.

The big idea. A **flood** happens when a river gets more water than its channel can carry, so the water spreads onto land that is usually dry. Johnstown had three dangers stacked together. First, very heavy rain. Second, steep hills and a narrow valley that funneled all that water into one place. Third, a **dam** that was not built and cared for well enough. A dam is useful because its **reservoir** stores water, but a dam must have a strong **spillway** so extra water can leave safely. When the South Fork Dam broke, the flood rose so fast that it was a **flash flood**. The moving water picked up houses, trees and railroad cars and pushed them like a giant bulldozer. Much of that wreckage piled up against the great Stone Bridge below the town, and the pile caught fire.

In the world today. Today many states inspect large dams, and dams are designed with spillways big enough for the worst storms. The National Weather Service sends out flood watches and warnings by radio, television and phone. On the day of the flood, warnings were sent by telegraph, but many people had heard false alarms about the dam before and did not believe them. Today we know to take every warning seriously. Remember the weather service’s rule, “Turn Around, Don’t Drown.” Just 15 centimeters (6 inches) of fast-moving water can knock over an adult, and about 30 centimeters (12 inches) of rushing water can carry away most cars.

God’s handiwork. God made water heavy. One cubic meter of water, a box about as wide as a kitchen table and as tall as your waist, weighs about 1,000 kilograms (about 2,200 pounds). The same power that turns a mill wheel can tear down a house if people forget to respect it. After the flood, neighbors all over America sent food, clothes, lumber and money, and Clara Barton came with the new American Red Cross to help. In the worst of times, people made in God’s image showed love by carrying one another’s burdens.



The flood's path: from the South Fork Dam down the Little Conemaugh River to Johnstown, about 23 km (14 mi).

PICTURE STUDY



Johnstown after the Flood, Unknown photographer, June 1889 · Photograph · Johnstown Flood National Memorial (National Park Service), South Fork, Pennsylvania

In the days after the flood, photographers came to Johnstown with heavy cameras on wooden stands. Their pictures were printed in newspapers and sold across the country, and they helped Americans understand what had happened and why help was needed. Many of these

photographs are kept today at the Library of Congress and at the Johnstown Flood National Memorial, the national park at the site of the dam.

A photograph like this is also a scientific record. Engineers and historians still study these pictures to see how high the water reached, which buildings stood, and where the wreckage piled up.

Look closely

- Find a house that was moved off its foundation. Which way do you think the water was flowing?
- Look for tree trunks and boards. Where did they pile up?
- Find any building that is still standing. What might have made it stronger than the others?
- Look at the people. What do you think they are doing?

Talk about it

1. What does this photograph tell you about how strong moving water can be?
2. If you were an engineer looking at this picture in 1889, what would you want to measure?
3. How could people far away help the families of Johnstown?

> **Safety first.** Do this experiment outdoors, in a bathtub or on a towel-covered table, and wipe up spills right away so no one slips. Never play near real creeks, storm drains or rivers when they are running high after rain.

EXPERIMENT: MODEL DAM BREAK: DOES A SPILLWAY HELP?

Engineers said the South Fork Dam would have had a better chance if its spillway had been large and clear. You will test that idea with sand dams in a pan. Question: *Does a spillway help an earthen dam survive a storm?* Write your prediction before you start.

You will need

- A long baking pan or plastic storage bin
- Damp sand or garden soil (about 4 cups)
- A paper cup with 3 small holes poked in the bottom (your “rain cloud”)
- A measuring cup and a pitcher of water
- A ruler, a timer, and 4 small blocks or toy houses
- Lab notebook and pencil

Steps

1. Prop one end of the pan up about 3 centimeters (1 inch) on a book so it slopes like a valley.

2. Near the high end, build a sand dam across the pan, 5 centimeters (2 inches) tall. Pat it firm. Set your toy houses near the low end. This is your “town.”
3. Trial 1 (no spillway): Pour 2 cups of water behind the dam to make a lake. Then hold the rain cloud cup over the lake and fill it again and again with the same amount of water. Start the timer.
4. Watch closely. Record the time when water first flows over the top, and the time when the dam breaks open. Record how far the houses moved.
5. Rebuild the dam exactly the same size with the same sand. Trial 2 (with spillway): Use your finger to carve a small channel 1 centimeter deep around one end of the dam, and line it with a strip of foil so it does not wash out.
6. Repeat the same lake and the same rain. Record the times and the houses again.
7. Make a table in your notebook: Trial, Spillway?, Time water went over the top, Did the dam break?, What happened to the town?
8. Write one sentence: Was your prediction right? Why?

Tips

- What we change: spillway or no spillway. What we keep the same: amount of sand, dam height, slope, size of the lake, and the rain cup. What we measure: time until overtopping and whether the dam breaks.
- Try a third trial with a spillway that you “clog” with small twigs, like the fish screens at South Fork. What happens?

Check your work

- I kept everything the same except the spillway.
- I recorded times and results in a table.
- I can explain why a spillway protects a dam.

FIELD NOTEBOOK

1. Draw a side view of an earthen dam with its lake behind it. Label the dam, the reservoir, the spillway and the outlet pipes at the bottom.
2. Copy the valley map from the lesson. Use arrows to show the path of the flood from the dam to Johnstown, and write the distance.
3. Make a T-chart titled “Why the Dam Failed” with two columns: Nature (the rain, the valley) and People (the repairs and changes).

> **From history.** Clara Barton, who had nursed wounded soldiers during the Civil War, founded the American Red Cross in 1881. When she heard about Johnstown, she traveled there and arrived on June 5, 1889, five days after the flood. She and her helpers stayed about five months. They built large wooden shelters where homeless families could live, handed out food and clothing, and helped people begin again. Johnstown was the first great disaster relief work of the American Red Cross, and it showed the whole country what the young organization could do.

WORKED EXAMPLES

Example 1. The flood wave traveled about 23 kilometers (14 miles) from the South Fork Dam to Johnstown in about 1 hour. About how fast was it moving? How does that compare with a bicycle going 15 kilometers per hour?

(Use the map or drawing "Use the distance on the map: about 23 km (14 mi)." shown earlier in this lesson.)

1. Speed means distance divided by time.
2. 23 kilometers ÷ 1 hour = 23 kilometers per hour (14 miles per hour).
3. Compare: 23 is more than 15, so the flood moved faster than a child on a bicycle.
4. 23 − 15 = 8, so the water was about 8 kilometers per hour faster.

Answer: About 23 kilometers per hour (14 miles per hour), about 8 kilometers per hour faster than the bicycle. A person on foot could not outrun it.

Example 2. The South Fork Dam was about 22 meters (72 feet) high. One story of a house is about 3 meters (10 feet) tall. About how many stories tall was the dam?

1. Divide the height of the dam by the height of one story.
2. 22 ÷ 3 = 7 with 1 meter left over, so a little more than 7.
3. Check with feet: 72 ÷ 10 = 7.2. The answers agree.

Answer: About 7 stories tall, as high as a seven-story building.

PRACTICE

1. EASY What two streams meet at Johnstown?
2. EASY What is a spillway, and what does it do for a dam?
3. MEDIUM Name two things people did, or failed to do, that made the South Fork Dam weaker.
4. MEDIUM If a flood wave moved at 23 kilometers per hour, how long would it take to travel 46 kilometers?
5. MEDIUM Here is a pretend rain gauge record for one stormy day in four towns: Hilltop 18 cm, Riverside 12 cm, Pine Hollow 22 cm, Mill Creek 9 cm. (a) Which town got the most rain? (b) How much more rain fell in Pine Hollow than in Mill Creek? (c) List the towns from most rain to least.
6. HARD Maya wants to test whether a taller sand dam holds back water longer than a shorter one. Name the variable she should change, two things she should keep the same, and what she should measure.
7. HARD One cubic meter of water weighs about 1,000 kilograms. A small swimming pool holds 3 cubic meters of water. About how much does the water weigh?

8. CHALLENGE Warnings were sent to Johnstown by telegraph before the flood, but many people did not leave. Explain why, and write one lesson for us today.

COMMON MISTAKES

- Thinking a flood needs a hurricane or the ocean. Most floods in America come from rivers and heavy rain far from any coast.
- Thinking the rain alone caused the Johnstown Flood. The rain was very heavy, but the weak, poorly repaired dam turned a bad flood into a disaster.
- Thinking shallow moving water is safe to walk or drive through. Just 15 cm (6 in) of fast water can knock a person down.

Make it a game · Turn Around, Don't Drown. A parent reads out a flood situation, such as "The road ahead has water flowing across it," "A flood warning comes on the radio at night," or "Your friend wants to play in the rushing ditch after a storm." If the safe choice is to turn back or go to high ground, shout "Turn around!" and walk backward three steps. If the situation is safe, give a thumbs-up. Earn a point for each right answer and one bonus point if you can explain why. Play to ten points.

Scripture. "Bear ye one another's burdens, and so fulfil the law of Christ." (Galatians 6:2, KJV)

After the flood, people from all over the nation sent help, and Clara Barton's workers stayed for months. When disaster comes, Christians are called to carry the loads of neighbors who cannot carry them alone.

Practice answers

1. The Little Conemaugh River and Stony Creek. Together they form the Conemaugh River.
2. A spillway is a channel that lets extra water flow safely past a dam, so the water does not pour over the top of the dam and wash it away.
3. Any two: the outlet pipes at the bottom were removed and never replaced; the top of the dam was lowered for a road; fish screens were put across the spillway and clogged with branches; the sagging middle was patched with dirt instead of being properly rebuilt.
4. 46 ÷ 23 = 2, so 2 hours.
5. (a) Pine Hollow. (b) 22 − 9 = 13 cm more. (c) Pine Hollow (22), Hilltop (18), Riverside (12), Mill Creek (9).
6. Change: the height of the dam. Keep the same (any two): the kind and amount of sand, the width of the dam, the slope of the pan, how fast the water is poured, the amount of water. Measure: how long each dam holds before water goes over the top or it breaks.
7. 3 × 1,000 = 3,000 kilograms (about 6,600 pounds), heavier than a car.
8. Many people had heard false alarms about the dam in past years, so they thought this was another one; the streets were also already flooded and it was hard to move. Lesson: take every flood warning seriously and get to high ground, because you cannot tell in advance which warning is the real one.

6.2 Levees and Dams

OBJECTIVES

- Explain how levees, dams and floodways each help control river floods, and name one weakness of each.
- Describe the Great Mississippi Flood of 1927 and what engineers built afterward to prevent another one like it.
- Use measurements to find how much room is left on a levee and compare the heights of dams and other structures.

Warm-up. Run a thin stream of water from the faucet into a shallow baking pan. Now use your two hands, held on their edges, to make a narrow channel in the pan. What happens to the water's height between your hands? Move your hands farther apart. What changes? Squeezing a river makes it rise higher.

Video. Coming soon. How levees and dams control floods for kids: search USGS, the U.S. Army Corps of Engineers, the Bureau of Reclamation (Hoover Dam), NOAA SciJinks, Science Max, and stream-table river models from university geology departments.

KEY TERMS

levee
A long wall or bank of earth built along a river to keep flood water in the river channel.

natural levee
A low ridge of sand and mud that a river builds along its own banks when floods drop their heaviest sediment right next to the channel.

floodplain
The flat land beside a river that the river covers when it floods.

floodway
A path engineers leave open on purpose so extra flood water can leave the main river and flow somewhere safer.

hydroelectric power
Electricity made when falling water from a dam spins machines called turbines.

CORE IDEAS

The story. In the spring of 1927, after months of heavy rain, the Mississippi River rose higher than anyone living had ever seen. People along the river worked day and night stacking sandbags on the long earthen walls, called **levees**, that kept the water out of their farms and towns. On April 21, 1927, at a place called Mounds Landing in Mississippi, the levee broke. A torrent of brown water poured through the gap and spread across the land for miles. Up and down the river, levees failed in many places. The water covered about 70,000

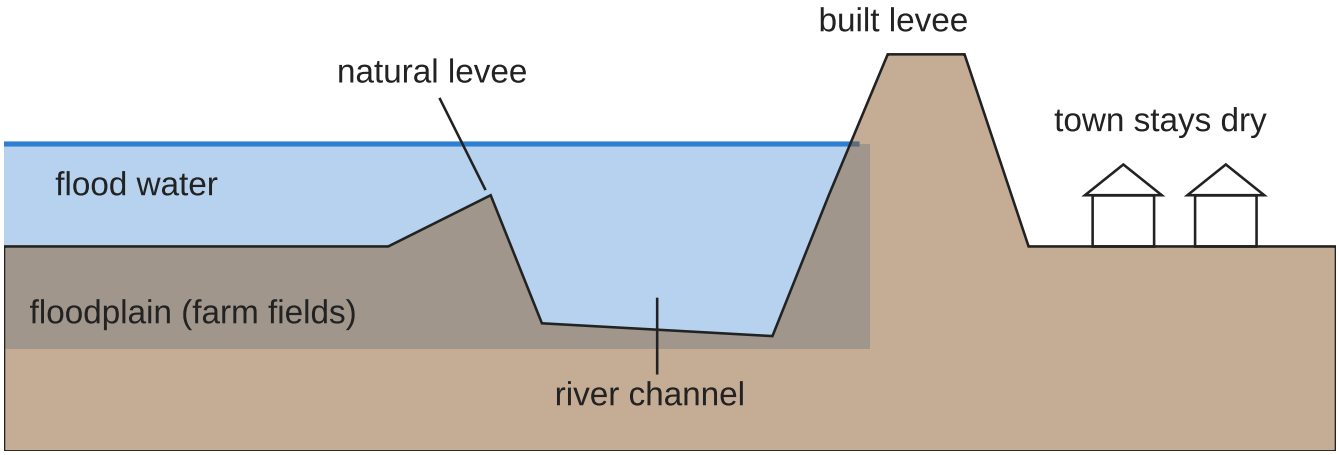
square kilometers (27,000 square miles), and hundreds of thousands of people had to leave their homes, many of them living in tents on top of the levees for weeks. It was one of the greatest floods in American history.

How they figured it out. Before 1927, many people believed that levees alone could hold the Mississippi if they were built high enough. The great flood proved them wrong. A levee squeezes a river into a narrow path, so in a flood the water climbs higher, and if a levee breaks, the water rushes out all at once. So the next year Congress passed a law to control the river in a new way: with levees *and* with **floodways**, open paths where extra water could be let out safely. One of these, the Bonnet Carré Spillway above New Orleans, was finished in 1931. When the river is dangerously high, workers open its gates and send part of the Mississippi into a lake instead of through the city. Around the same time, engineers in the West were building a giant dam to tame another wild river, the Colorado. Hoover Dam, finished in 1936, is a curved wall of concrete 221 meters (726 feet) high. The lake behind it, Lake Mead, catches the spring floods from melting mountain snow and lets the water out slowly all year.

The big idea. Rivers build their own levees. When a river floods, the water slows down as soon as it leaves the channel, and the heaviest sand drops right beside the bank. Flood after flood, this makes a low ridge called a **natural levee**. Finer mud travels farther and settles on the flat **floodplain**, which is why floodplains make such rich farmland. People copy the river by building taller levees of packed earth. A **dam** works differently: it stops the river and stores water in a reservoir, then releases it a little at a time. Many dams do several jobs at once: they hold back floods, store water for cities and farms, and make **hydroelectric power** as water falls through turbines. No single tool is perfect. Levees can break or be overtopped. Dams must be inspected and need good spillways, as Johnstown taught. The wisest plans combine levees, dams and floodways, and they leave some floodplains as fields and parks where the river can spread out without hurting anyone.

Try it and see. You can see why levees make water rise. In this lesson’s project you will carve a river into sand, build levees beside it, and measure how deep the water gets with and without them. Watch where the water goes when a levee breaks.

God’s handiwork. God gave people the job of caring for the earth and using it wisely (Genesis 1:28). The same river that floods also carries fresh soil to farms, water to cities and boats full of goods. When engineers study how rivers really behave and build to work with them, they are using the minds God gave them to protect their neighbors.



A river in flood: the natural levee is too low, but the built levee protects the town.

PICTURE STUDY



Boulder Dam (Hoover Dam) from Across the Colorado River, Ansel Adams, 1941 · Black-and-white photograph · National Archives, Washington, D.C. (Ansel Adams Photographs of National Parks and Monuments)

Ansel Adams was an American photographer famous for his black-and-white pictures of the mountains and deserts of the West. In 1941 the U.S. Department of the Interior hired him to photograph national parks and other great places in the West, and he traveled to Black Canyon on the border of Arizona and Nevada to photograph the dam, then called Boulder

Dam. Because he made these pictures for the government, they belong to the public and are kept at the National Archives.

Adams loved strong shapes and sharp detail. Here the smooth curve of the dam, the straight lines of the power plant and the rough rock of the canyon stand side by side, a careful record that is also a work of art.

Look closely

- Find the curve of the dam. Which way does it bend, toward the lake behind it or toward you?
- Find the buildings at the bottom of the dam. That is the power plant, where falling water spins the turbines.
- Compare the size of the dam with the canyon walls. How did the builders use the canyon?
- Look for anything that shows how big the dam is, such as a road, a building or a person.

Talk about it

1. Why do you think the dam is curved instead of straight?
2. What jobs does a dam like this do for the people who live downstream?
3. How is this concrete dam different from the earthen dam at South Fork?

> **Safety first.** Do the project outdoors or in a tub, and wipe spills so no one slips. Never climb on real levees or dams or go near spillways, where fast water and strong currents can pull a person in.

EXPERIMENT: LEVEES IN A PAN: DO LEVEES MAKE THE RIVER RISE?

Engineers learned in 1927 that levees keep land dry but make the river run higher. You will test that idea. Question: *Does adding levees make the water in a river channel deeper?* Write your prediction first.

You will need

- A long baking pan or plastic bin, propped up 3 centimeters (1 inch) at one end
- Damp sand, plus a little modeling clay or play dough
- A pitcher, a measuring cup and water
- A ruler and a toothpick or craft stick marked in centimeters
- Small blocks for a “town” and a “farm”
- Lab notebook and pencil

Steps

1. Spread the sand flat and carve a winding river channel about 2 centimeters (1 inch) wide and 1 centimeter deep from the high end to the low end.

2. Mark a measuring spot halfway down the channel. Put the town blocks on one side of the river near the spot and the farm blocks on the other side.
3. Trial 1 (no levees): Pour 2 cups of water slowly and steadily into the top of the channel. At the measuring spot, use your marked stick to measure how deep the water gets. Note whether the town and farm get wet.
4. Smooth the sand and carve the same channel again. Trial 2 (levees): Build low walls of sand about 2 centimeters high along both banks. Pour the same 2 cups the same way and measure the depth at the same spot.
5. Trial 3 (one weak spot): Rebuild the levees, but make one short section on the farm side low and thin. Pour again. Where does the water go?
6. Record a table: Trial, Levees?, Water depth at the spot (cm), Did the town flood?, Did the farm flood?
7. Write two sentences about what levees do well and what can go wrong.

Tips

- What we change: levees or no levees. What we keep the same: the channel, the slope, the amount of water and how fast it is poured. What we measure: the water depth at one spot.
- Bonus: build one levee from sand and one from clay. Which holds better? This is why real levees are made of tightly packed soil with clay in it.

Check your work

- I measured the water depth at the same spot each time.
- I can explain why levees make the water in the channel rise.
- I saw what happens to land behind a levee when it breaks.

FIELD NOTEBOOK

1. Draw a cross-section of a river with a natural levee on one side and a built levee on the other. Label the channel, floodplain, natural levee and built levee.
2. Draw a dam with its reservoir. Use arrows to show three jobs the dam does: flood control, water storage and electricity.
3. If you live near a river, look at it with a parent. Is there a levee, a floodwall or a wide floodplain? Sketch what you see and write the date.

> **From history.** People have watched river floods for thousands of years. In ancient Egypt, the Nile flooded every summer and spread rich black mud over the fields, and farmers planted as soon as the water went down. The Egyptians built stone measuring wells and stairways, called nilometers, with marks on the walls to record how high the Nile rose. A flood that was too low meant a poor harvest; a flood that was too high could wash away villages. By measuring the river every year, officials could plan for food and taxes. It was one of the first long records of river heights in the world.

WORKED EXAMPLES

Example 1. A river gauge shows the water is 8.5 meters deep. The top of the levee is 10 meters above the river bottom. The river is rising 25 centimeters every hour. How much room is left, and about how many hours until the water reaches the top of the levee?

(Use the map or drawing "The room between the water and the top of the levee is what engineers watch in a" shown earlier in this lesson.)

1. Room left: 10 m − 8.5 m = 1.5 m.
2. Change to centimeters so the units match: 1.5 m = 150 cm.
3. Hours: 150 cm ÷ 25 cm per hour = 6 hours.
4. In U.S. units: about 5 feet of room, rising about 10 inches an hour.

Answer: 1.5 meters (150 cm, about 5 feet) of room is left, enough for about 6 hours if the river keeps rising at the same rate. That is time to sandbag and to warn people to move to high ground.

Example 2. Hoover Dam is 221 meters (726 feet) high. The Statue of Liberty, from the ground to the tip of its torch, is about 93 meters (305 feet). About how many times taller is the dam?

1. Divide the bigger height by the smaller one: 221 ÷ 93.
2. 93 × 2 = 186, and 93 × 3 = 279. 221 is between them.
3. 221 − 186 = 35 left over, which is less than half of 93, so the answer is a little more than 2.
4. Check with feet: 726 ÷ 305 is also a little more than 2.

Answer: A little more than 2 times as tall (about 2.4 times). You could stack two Statues of Liberty against the dam and still not reach the top.

PRACTICE

1. EASY What is a levee?
2. EASY Name three jobs a large dam like Hoover Dam can do.
3. MEDIUM How does a river build a natural levee?
4. MEDIUM Why can a levee make a flood worse for people downstream or on the other bank?
5. MEDIUM A river gauge read these depths at noon each day: Monday 4 m, Tuesday 5 m, Wednesday 7 m, Thursday 8 m, Friday 6 m. (a) On which day was the river highest? (b) Between which two days did it rise the most? (c) If the levee top is 9 m, how much room was left on the highest day?

6. HARD Sam wants to find out whether levees made with clay hold back water better than levees made with sand. Describe a fair test. What does he change, what does he keep the same, and what does he measure?
7. HARD A levee has 120 cm of room left. The river is rising 20 cm per hour. How many hours until it reaches the top?
8. CHALLENGE After the 1927 flood, engineers decided to use floodways as well as levees. Explain in two or three sentences why that was a wise change.

COMMON MISTAKES

- Thinking a levee makes land completely safe. Levees can be overtopped or break, so people behind them still need flood plans and warnings.
- Thinking floods only do harm. Floods also spread fresh soil on floodplains, which is why river valleys are such good farmland.
- Thinking dams are only for electricity. Most large dams also control floods and store water for drinking and farming.

Make it a game · Levee, Dam or Floodway?. A parent describes a flood-control job, such as “Store spring snowmelt and let it out slowly,” “Keep the river from spilling into a town,” or “Send extra water into a lake instead of through the city.” Shout the tool that fits: “Levee!”, “Dam!” or “Floodway!” Make a motion for each: arms in a wall for levee, arms crossed for dam, one arm sweeping out for floodway. Score a point for each right answer. After ten rounds, switch and let the child describe the jobs.

Scripture. “And said, Hitherto shalt thou come, but no further: and here shall thy proud waves be stayed?” (Job 38:11, KJV)

God speaks to Job about setting limits for the sea. Engineers build levees and dams to set small limits for rivers, but only God commands the waters perfectly. Our work should make us humble and careful.

Practice answers

1. A long wall or bank of earth built along a river to keep flood water inside the channel.
2. Any three: hold back floods, store water for cities, store water for farms, make hydroelectric power, make a lake for boating and fishing.
3. When the river floods, the water slows down as soon as it spills out of the channel, and the heaviest sand drops right next to the bank. After many floods, this builds a low ridge along the river.
4. A levee squeezes the river into a narrow channel, so the water rises higher and flows faster. That extra water must go somewhere, and if a levee breaks, the water rushes out all at once.
5. (a) Thursday. (b) Tuesday to Wednesday, a rise of 2 m. (c) $9 - 8 = 1$ m (100 cm, about 3 feet).
6. Change: the material of the levee (clay or sand). Keep the same: the size and shape of the levees, the channel, the slope, the amount of water and how fast it is poured. Measure: how long each levee holds before water leaks through or breaks it, or how much water leaks out. He should do each test more than once.

7. 120 ÷ 20 = 6 hours.
8. Levees alone made the river rise higher and higher, and when they broke, water poured out without warning. A floodway gives the extra water a safe place to go on purpose, so the water in the main river drops and the levees protecting cities do not have to hold back as much.

6.3 Watersheds

OBJECTIVES

- Define a watershed and a divide, and trace the path a raindrop takes from a hillside to the sea.
- Tell how John Wesley Powell explored the Colorado River in 1869 and why he urged people to think in watersheds.
- Calculate how much water falls on an area in a storm and explain why pavement makes more runoff than forest soil.

Warm-up. Hold a book open in a tent shape over the sink, like a roof. Drip water slowly from a spoon onto the very top of the spine. Which way does each drop go? Now drip a little to the left and a little to the right of the top. The spine is a tiny “divide”: it decides which side the water flows to.

Video. Coming soon. What is a watershed for kids, crumpled-paper watershed model, and John Wesley Powell’s 1869 Colorado River expedition: search USGS Water Science School, the EPA, the National Park Service (Grand Canyon), NOAA, SciShow Kids and Homeschool Pop.

KEY TERMS

watershed
All the land that drains into one river, lake or bay. Rain that falls anywhere in a watershed ends up flowing to the same place. Also called a drainage basin.

divide
The high ground, such as a ridge or mountain crest, that separates one watershed from the next.

tributary
A smaller stream or river that flows into a larger one.

runoff
Rain or melted snow that flows over the ground instead of soaking in.

mouth
The place where a river ends by flowing into a larger river, a lake or the sea.

CORE IDEAS

The story. On May 24, 1869, John Wesley Powell pushed off from Green River, Wyoming, with nine men in four wooden boats. Powell was a teacher and scientist who had lost his right arm in the Civil War, but he was determined to explore one of the last unmapped places in America: the canyons of the Green and Colorado Rivers. For more than three months the party rode roaring rapids, carried boats around falls, lost one boat and much of their food,

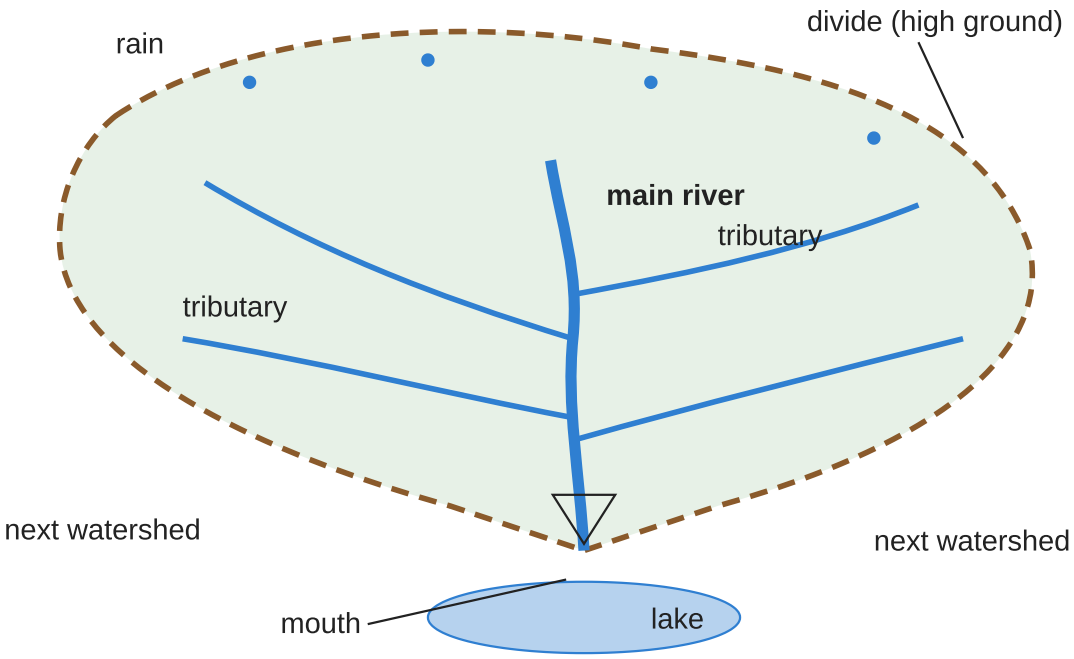
and measured the river as they went. Powell climbed the cliffs with one arm to take readings and to look out over the land. In late August the boats that were left floated out of the Grand Canyon. They were the first people known to travel the whole canyon by river.

How they figured it out. From the canyon rims Powell could see how the land was shaped. Every side canyon, every gully and every dry wash sloped down toward the great river. Rain that fell on a mesa many miles away would one day reach the Colorado. Powell realized that a river and all the land that drains into it work together as one system. Years later, in a famous report to the government, he urged that new settlements in the dry West be planned around these natural drainage areas, so that people sharing a river would plan together how to use its water. Today we call that area of land a **watershed**.

The big idea. A watershed is like a giant bowl. Its rim is the **divide**, the high ground on every side. Rain that falls inside the rim runs downhill as **runoff**, gathers in small streams, and the small streams flow into bigger ones as **tributaries**. At last all the water leaves the bowl at one place, the river's **mouth**. Small watersheds fit inside bigger ones like nesting cups. The watershed of the creek behind a school may be part of a river's watershed, which is part of a still bigger one. The Mississippi River's watershed drains all or part of 31 states and two Canadian provinces, so rain falling in Montana and rain falling in Pennsylvania can meet in the same river and reach the Gulf of Mexico together. Rivers do not always flow south. They flow downhill, and the Red River of the North flows north toward Hudson Bay in Canada.

Try it and see. Watersheds explain floods. When it rains hard all over a big watershed, all the tributaries pour into the main river at once, and the river rises far downstream, even where the sky is clear. The ground matters too. Forest soil and grass act like a sponge and soak up much of the rain. Roofs, roads and parking lots are hard, so nearly all the rain becomes runoff that rushes into storm drains and streams. That is why a city street can flood quickly in a thunderstorm. In the project you will build a model watershed from crumpled paper and watch the rain find its way downhill.

God's handiwork. The psalmist praised God, who "sendeth the springs into the valleys." Every valley is shaped to gather water and carry it where it is needed. Whatever we pour on the ground in our yards, such as oil, soap or fertilizer, travels with the runoff to the creek and then to the river. Caring for our own small piece of the watershed is one way to obey God's call to keep and tend His world (Genesis 2:15).



A watershed: everything inside the divide drains to the same river mouth.

⏳ Thinking About Time

What the sign says. What the sign says: Many park signs and textbooks say the Colorado River slowly carved the Grand Canyon, grain by grain, over millions of years, and that the rock layers in its walls were laid down over even longer ages.

What we observe. What we observe: Rivers really do cut into rock and carry sand and mud away, and the canyon walls show many flat layers stacked one on another. We also see that big floods can carve quickly: in 1982 a mudflow from Mount St. Helens in Washington cut deep channels through fresh volcanic rock in a single day.

How Christians read it. How Christians read it: Many creation geologists think most of the canyon's layers were laid down during the Flood of Noah's day, and that the canyon was carved quickly as huge amounts of water drained off the land at the end of the Flood or soon after, rather than slowly over vast ages.

Try it. Pour a cup of water slowly onto a sand pile, then pour a whole pitcher fast onto another. Which cuts a deeper channel?

Genesis 8:3

PICTURE STUDY



The Chasm of the Colorado, Thomas Moran, 1873–1874 · Oil on canvas · Smithsonian American Art Museum, Washington, D.C. (lent by the U.S. Department of the Interior)

Thomas Moran traveled to the Grand Canyon in 1873 with John Wesley Powell, who had become a hero for his river journey. Moran sketched from the rim while Powell explained what they were seeing. Back in his studio Moran painted this enormous picture, more than 3.5 meters (12 feet) wide. Congress bought it and hung it in the Capitol, and it helped Americans imagine a place most of them would never see.

Moran wanted people to feel how vast the canyon is and how weather moves through it. Look for the storm that is passing over the canyon.

Look closely

- Find the storm clouds and the rain. Where will that rain go after it hits the rocks?
- Look for the river at the bottom of the canyon. How large or small does it look?
- Find the layers in the canyon walls. How many different colors can you see?
- Find where the light is brightest. Where are the darkest shadows?

Talk about it

1. How does this painting show a watershed at work?
2. Why do you think Congress wanted this painting in the Capitol?
3. If you stood on this rim, what would you want to draw or measure first?

> **Safety first.** Use washable markers and do the project on a tray or outdoors. Wipe up water so no one slips. Never go into a storm drain or culvert, even when it looks dry, because water can rush through it suddenly.

EXPERIMENT: CRUMPLED-PAPER WATERSHED

You will make a model of land with hills and valleys and watch where the rain goes. Question: *Can I predict where rain will collect by finding the divides first?* Then you will run a second small test on runoff.

You will need

- A sheet of white paper or light cardboard, crumpled and then partly opened
- A baking tray
- Washable markers: brown, blue and one other color
- A spray bottle of water
- Two sponges, a plastic lid or tray the same size as one sponge, two bowls and a measuring cup (for the runoff test)
- Lab notebook and pencil

Steps

1. Crumple the paper into a ball, then open it partway so it has ridges and valleys. Set it on the tray.
2. Trace the highest ridges with a brown marker. These are your divides.
3. With a blue marker, draw where you *predict* streams will flow and where water will collect.
4. Put three dots of a third color on different hillsides. These are “pollution,” like oil or fertilizer.
5. Spray “rain” evenly over the whole model, the same number of sprays all over, about 20 sprays. Watch where the water flows and where the colored dots travel.
6. Compare: Did the water follow your blue lines? Which low spot collected each colored dot? Record what happened.
7. Runoff test: Hold a damp sponge (forest soil) at a slant over one bowl and the plastic lid (pavement) over the other bowl. Slowly pour 1/2 cup of water over each. Measure how much water runs off into each bowl.
8. Record a table: Surface, Water poured, Water that ran off. Write which surface makes more runoff and why.

Tips

- In the runoff test, what we change: the surface. What we keep the same: the amount of water, how fast it is poured, the slant. What we measure: the water that runs off.
- Notice how the colored dots from different hills can end up in the same valley. Pollution anywhere in a watershed travels downstream.

Check your work

- I marked divides and predicted streams before the rain.
- I can explain where the colored “pollution” went and why.

- I measured runoff from two surfaces and compared them.

FIELD NOTEBOOK

1. Draw the diagram of a watershed. Label the divide, three tributaries, the main river and the mouth.
2. Walk around your house or yard after a rain with a parent. Draw arrows on a sketch map showing where the water flows. Where does it leave your yard?
3. With a parent’s help, look up the name of the creek or river your town drains into. Write the chain of rivers your rain travels through all the way to the ocean.

> **From history.** Powell lost his right arm at the Battle of Shiloh in 1862, yet only seven years later he led the first known trip through the Grand Canyon by boat. He went down the river again in 1871 and 1872 with a photographer and mapmakers, and later became the director of the U.S. Geological Survey, the government office that still maps America’s rivers and measures their flow today. USGS stream gauges on thousands of rivers report water levels every few minutes, carrying on the careful measuring Powell started.

WORKED EXAMPLES

Example 1. When 1 centimeter of rain falls on 1 square meter of ground, that is 10 liters of water. A roof covers 50 square meters. A storm drops 2 centimeters of rain. How many liters of water run off the roof?

1. Find the water on 1 square meter: 2 centimeters of rain is 2 × 10 = 20 liters.
2. Multiply by the number of square meters: 20 liters × 50 = 1,000 liters.
3. Check: 1,000 liters is about 264 gallons, enough to fill about five bathtubs.

Answer: 1,000 liters (about 264 gallons) of water runs off one roof in one storm. Picture every roof and street in a town, and you can see why streams rise so fast in a city.

Example 2. A raindrop falls on a hill near Johnstown, Pennsylvania, and runs into the Conemaugh River. The Conemaugh flows into the Kiskiminetas River, the Kiskiminetas flows into the Allegheny River, the Allegheny joins the Ohio River at Pittsburgh, and the Ohio flows into the Mississippi. Where does the raindrop finally reach the sea, and how many rivers does it travel through?

(Use the map or drawing "Small streams join bigger rivers, which join bigger rivers still." shown earlier in this lesson.)

1. List the rivers in order: Conemaugh, Kiskiminetas, Allegheny, Ohio, Mississippi.
2. Count them: 5 rivers.
3. The Mississippi's mouth is at the Gulf of Mexico, below New Orleans.
4. Each river is a tributary of the next, so Johnstown sits inside the giant Mississippi watershed.

Answer: It reaches the Gulf of Mexico after traveling through 5 rivers. Johnstown is part of the Mississippi River's watershed.

PRACTICE

1. EASY What is a watershed?
2. EASY What is the high ground between two watersheds called?
3. MEDIUM True or false: All rivers flow south. Explain.
4. MEDIUM One centimeter of rain on 1 square meter is 10 liters. How many liters fall on a 6-square-meter garden in a 3-centimeter rain?
5. MEDIUM A class poured 500 mL of water on each surface and measured the runoff: parking lot model 450 mL, lawn model 200 mL, forest soil model 50 mL. (a) Which surface had the most runoff? (b) How much water soaked into the lawn? (c) Why would a town with many parking lots flood faster?
6. HARD Lena wants to test whether grass or bare soil lets more water run off a slope. Name the variable she changes, two things she keeps the same, and what she measures. What could her control be?
7. HARD It rained hard upstream in a big watershed, but it did not rain at all in a town far downstream. Why might the town still flood a day or two later?
8. CHALLENGE A family washes their car in the driveway with soap. Using the word watershed, explain where the soapy water may end up and what they could do instead.

COMMON MISTAKES

- Thinking a watershed is a building or a shed for water. It is an area of land.
- Thinking rivers always flow south. Rivers flow downhill in any direction.
- Thinking only people who live by a river live in a watershed. Every place on land is in some watershed.

Make it a game · Which Way, Raindrop?. Make a “divide” with a line of pillows down the middle of the room. Label one side “Atlantic” and the other “Pacific.” A parent calls out where a raindrop lands, such as “just east of the pillows” or “right on top of the pillows.” The child, playing the raindrop, rolls or walks downhill to the correct side. For the top of the divide, the child must say “It could go either way!” For an extra point, name a tributary or river the drop might pass through. Play to ten points.

Scripture. “He sendeth the springs into the valleys, which run among the hills.” (Psalm 104:10, KJV)

Psalm 104 praises God for ordering the waters of the earth. Valleys gather springs and streams and carry them where plants, animals and people need them. A watershed is part of that order.

Practice answers

1. All the land that drains into one river, lake or bay. Rain that falls anywhere in it flows to the same place.
2. A divide.
3. False. Rivers flow downhill, in whatever direction the land slopes. The Red River of the North flows north toward Hudson Bay.
4. 3 cm × 10 L = 30 L per square meter; 30 × 6 = 180 liters.
5. (a) The parking lot. (b) 500 − 200 = 300 mL soaked in. (c) Hard surfaces let very little water soak in, so most of the rain rushes straight into drains and streams at once.
6. Change: the surface (grass or bare soil). Keep the same (any two): the slope, the size of the tray, the amount of water, how fast it is poured, how wet the soil starts. Measure: the amount of water that runs off. A control could be a plain plastic tray with no soil, to show how much runs off when nothing soaks in.
7. All the rain that fell inside the watershed flows downhill through tributaries into the main river. The water takes time to travel, so the river rises at the downstream town later, even under clear skies.
8. The soapy runoff flows down the driveway into the storm drain, which empties into a creek in the same watershed, then into larger rivers. They could wash the car on the grass, where the soil soaks up and filters the water, or use a car wash that cleans its water.

6.4 Flood-Proof Model House

OBJECTIVES

- Name and explain four ways to protect a house from floods: build on high ground, raise it up, seal it, or let water pass through safely.
- Explain what a “100-year flood” really means.
- Design, build and test a model house in a fair test, record data in a table and graph, and find an average.

Warm-up. Float an empty plastic container with its lid on in a sink of water. Push it down and let go. Now put a few coins or a small rock in it and try again. A house that is not tied down can float like the empty container! Talk about it: what two things must a flood-proof house do? (Stay dry inside, and stay put.)

Video. Coming soon. How to make a house flood resistant for kids, homes on stilts, and the Great Flood of 1993: search FEMA, NOAA, the National Weather Service, the U.S. Army Corps of Engineers, Science Max, and engineering design challenges from STEM education channels.

KEY TERMS

elevation
How high something is above the ground or above sea level. Raising a house’s elevation keeps its floors above flood water.

stilts
Strong posts or piers that hold a building up off the ground so water can flow underneath.

flood vent
An opening in the lower wall of a building that lets flood water flow in and out, so the water does not push the walls over.

100-year flood
A flood so big that it has a 1 in 100 chance of happening in any single year. It can happen two years in a row.

buoyancy
The upward push of water on an object. Buoyancy can lift and float away a house that is not anchored down.

CORE IDEAS

The story. In the summer of 1993, rain fell on the middle of America week after week. The Mississippi and Missouri Rivers and their tributaries rose and stayed high for months in what became known as the Great Flood of 1993. Levees broke in many places. In August, the water broke through the levee protecting Valmeyer, Illinois, a small town on the flat

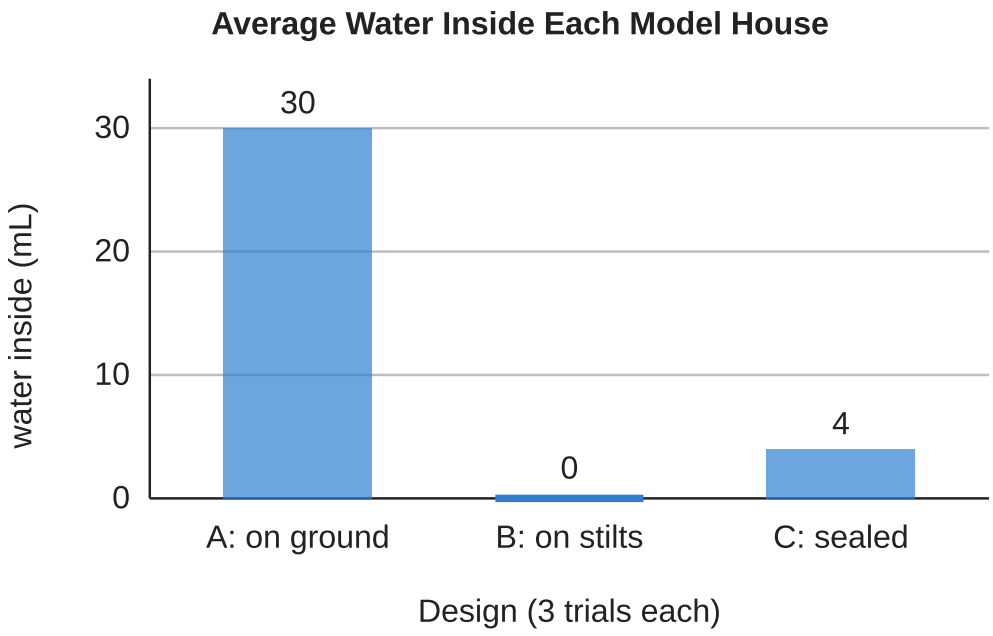
floodplain of the Mississippi south of St. Louis. Muddy water filled the homes, the school and the stores. When it finally drained away, the people of Valmeyer made a bold choice. Instead of rebuilding in the same low place, the town voted to move. With help from the government, they built a new Valmeyer on the high bluffs above the valley, where the river cannot reach.

How they figured it out. People who live near water have found four main ways to keep their homes safe. The first and best is the one Valmeyer chose: *build on high ground*. The second is to *raise the house up*. Along the bayous of Louisiana and on many coasts, houses stand on **stilts** so flood water flows underneath. The third is to *seal the house*, using waterproof walls, flood doors and barriers so water cannot get in. This works only for shallow water, because deep water pushes very hard on walls. The fourth is to *let water pass through safely*. Builders put **flood vents** in garages and crawl spaces so water can flow in and out, keeping the push equal on both sides of the wall. They use materials that can get wet and be cleaned, and they move the furnace, water heater and electrical boxes up high.

The big idea. Engineers study river records to learn how high floods have reached in the past. A **100-year flood** is a flood that has a 1 in 100 chance of happening in any single year. It does not mean it comes only once every hundred years. It can happen two years in a row, just as you can roll a six on a die twice in a row. Many towns require new houses near rivers to have their floors above the 100-year flood level, plus a little extra height for safety. A flood-proof house must also stay put. Because of **buoyancy**, water pushes up on anything in it, and a house that is not bolted to a strong foundation can float off and be carried away. So a good design keeps water out of the living space, lets water flow past without knocking the house down, and anchors the house firmly to the ground.

Try it and see. In this lesson you will be the engineer. You will build three model houses from small boxes, put them through a flood in a tub, and measure which design keeps its floor dry. Real engineers test small models before they build big things, because it is much cheaper to learn from a soggy cardboard house than from a real one.

God’s handiwork. Jesus told of a wise man who built his house on a rock, and when “the floods came,” the house stood. It is wise to choose a safe place to build and to build well. Jesus meant even more: a life built on hearing and doing His words will stand when hard times come like a flood.



Sample results from three model house designs, averaged over three trials.

PICTURE STUDY



Flood at Port-Marly, Alfred Sisley, 1876 · Oil on canvas · Fitzwilliam Museum, Cambridge, England

Alfred Sisley was born in Paris to English parents and spent his life painting the villages along the Seine River in France. In the spring of 1876 the Seine flooded the little town of Port-Marly, west of Paris. Sisley set up his easel and painted the flood several times. In this picture an inn stands in the water while people use boats to get around the street.

Sisley was one of the Impressionist painters, who liked to paint outdoors and catch light and weather quickly with small brushstrokes. Notice how calm and quiet the scene is, even though the town is under water.

Look closely

- Find the inn. How high has the water risen on its walls? Would the people upstairs stay dry?
- Find the boats. What are people using them for?
- Look at the reflections in the water. What can you see reflected?
- Look at the sky. Does it look like the storm is over or still coming?

Talk about it

1. If you were an engineer, what would you change about this building to protect it from the next flood?
2. Why might people build a town right next to a river even though it floods?
3. How does this calm painting make you feel compared with the photograph of Johnstown?

> **Safety first.** Ask an adult to help cut cardboard or cartons with scissors. Do the flood test outdoors or in a bathtub and wipe up spills. In a real flood, never walk, swim or play in flood water; it can be fast, deep and dirty.

EXPERIMENT: DESIGN AND TEST A FLOOD-PROOF MODEL HOUSE

You will build three small houses that are the same size and shape, change only one thing about each, and flood them all the same way. Question: *Which design keeps the floor of the house driest in a flood?* Write your prediction before you test.

You will need

- Three small boxes the same size, such as single-serving milk or juice cartons cut in half, or small gift boxes
- Three squares of paper towel, cut to fit the floor of each box
- Craft sticks or pencils, tape, and a lump of modeling clay
- Plastic wrap or a plastic bag
- A plastic bin or bathtub, a pitcher of water and a ruler
- A medicine syringe or measuring spoons to measure water in milliliters
- Lab notebook and pencil

Steps

1. Build Design A (on the ground): a box with a paper towel floor, nothing else.
2. Build Design B (on stilts): the same box with four craft sticks taped to the corners so the floor stands 5 centimeters (2 inches) above the ground. Press the stilts into a lump

of clay so the house cannot float away.
3. Build Design C (sealed): the same box on the ground, wrapped tightly in plastic wrap and taped.
4. Weight or anchor Designs A and C with a little clay inside one corner so they do not float. Set all three houses in the dry bin.
5. Slowly pour water into the bin until it is 3 centimeters (a little more than 1 inch) deep. Measure with the ruler. Wait 2 minutes.
6. Lift each house out. Pour or squeeze any water inside into a cup and measure it in milliliters. Note whether the paper towel floor is dry, damp or soaked.
7. Dry everything, replace the paper towels, and repeat for 3 trials. Record each trial in a table: Design, Trial 1, Trial 2, Trial 3, Average (mL).
8. Find the average for each design and draw a bar graph. Write two sentences: Which design worked best? What would you improve?

Tips

- What we change: the design of the house. What we keep the same: box size, water depth, time in the water, anchoring. What we measure: milliliters of water inside and how wet the floor is.
- Challenge round: make a “moving flood” by gently pushing a wave of water across the bin with a spatula. Which houses stay put? This is why anchoring matters.
- To find an average, add the three trials and divide by 3.

Check your work

- I changed only one thing about each house.
- I did three trials and found the average for each design.
- I made a bar graph and explained which design worked best and why.

FIELD NOTEBOOK

1. Draw a side view of your best house in the flood. Label the water line, the floor, the stilts or seal, and the anchor.
2. Sketch four houses, one for each way to protect a home from floods: high ground, raised up, sealed, and letting water pass through. Write one sentence under each.
3. Look for flood-wise building in your town or in a book: houses on piers, high foundations, flood walls or vents. Draw one and write where you saw it.

> **From history.** In the 1850s and 1860s, the city of Chicago was built on low, wet ground near Lake Michigan, and its streets were often deep in mud and standing water. To lay sewers and drain the city, Chicago decided to raise its streets and buildings several feet. Workers placed hundreds of jackscrews under heavy brick buildings and turned them a little at a time, all together, until the buildings rose. A young man named George Pullman, who later became famous for his railroad sleeping cars, helped lift some of the buildings. It was one of the greatest building-raising projects in history.

WORKED EXAMPLES

Example 1. Records show the 100-year flood at a building site would reach 1.2 meters (4 feet) above the ground. The town requires the first floor to be 0.3 meters (1 foot) higher than that. How high must the floor be? If each stair step rises 15 centimeters (6 inches), how many steps lead up to the door?

1. Floor height: 1.2 m + 0.3 m = 1.5 m. In feet: 4 ft + 1 ft = 5 ft.
2. Change meters to centimeters: 1.5 m = 150 cm.
3. Steps: 150 cm ÷ 15 cm = 10 steps.
4. Check in inches: 5 ft = 60 inches; 60 ÷ 6 = 10 steps. The answers agree.

Answer: The floor must be 1.5 meters (5 feet) above the ground, reached by 10 steps.

Example 2. A student tested three model houses three times each and measured the water inside (in milliliters). Design A (ground): 30, 34, 26. Design B (stilts): 0, 0, 0. Design C (sealed): 6, 2, 4. Find each average. Which design worked best?

(Use the map or drawing "The bar graph makes the best design easy to see." shown earlier in this lesson.)

1. Design A: 30 + 34 + 26 = 90; 90 ÷ 3 = 30 mL.
2. Design B: 0 + 0 + 0 = 0; 0 ÷ 3 = 0 mL.
3. Design C: 6 + 2 + 4 = 12; 12 ÷ 3 = 4 mL.
4. Compare on the bar graph: B is lowest, C is next, A is highest.

Answer: Averages: A = 30 mL, B = 0 mL, C = 4 mL. Design B, the house on stilts, kept its floor driest.

PRACTICE

1. EASY Name the four main ways to protect a house from floods.
2. EASY What did the town of Valmeyer, Illinois, do after the Great Flood of 1993?
3. MEDIUM A neighbor says, "We had a 100-year flood last year, so we are safe for the next 99 years." Is that right? Explain.
4. MEDIUM Why do builders tie a house firmly to its foundation in a flood zone?
5. MEDIUM Find the average of these three trials of water inside a model house: 8 mL, 11 mL, 5 mL.
6. HARD Read this table of model test results (water inside, in mL). Design 1 (stilts 2 cm tall): 18. Design 2 (stilts 4 cm tall): 6. Design 3 (stilts 6 cm tall): 0. The water was 4 cm deep. (a) Which design kept the floor dry? (b) Why did Design 2 still get a little water? (c) Describe the pattern.

7. HARD Diego wants to test whether flood vents keep a model house from tipping over in moving water. What should he change, what should he keep the same, and what should he measure? What is his control?
8. CHALLENGE A family can afford only one change to their house in a flood zone: wrap the walls in waterproof material, or raise the house 1 meter on piers. The floods there are often 1 meter deep. Which would you choose, and why?

COMMON MISTAKES

- Thinking a “100-year flood” comes only once every hundred years. It has a 1 in 100 chance every year.
- Thinking a completely sealed house is always best. In deep water, the push of the water can break sealed walls, so letting water flow through the lowest level is sometimes safer.
- Forgetting buoyancy. A house can stay perfectly dry inside and still float away if it is not anchored.

Make it a game · Builder’s Choice. A parent names a building site: “a beach house where storm waves wash in,” “a town on a wide floodplain,” “a basement next to a creek,” “a hilltop farm.” The child quickly picks the best protection: high ground, stilts, seal it, or flood vents, and gives one reason. Use four cards or hand signs (hand flat up high for high ground, two fingers standing for stilts, hands wrapped together for seal, fingers wiggling through for vents). Earn a point for each good answer and a bonus for naming the danger, such as buoyancy or water pressure. Play to ten points.

Scripture. “Therefore whosoever heareth these sayings of mine, and doeth them, I will liken him unto a wise man, which built his house upon a rock: And the rain descended, and the floods came, and the winds blew, and beat upon that house; and it fell not: for it was founded upon a rock.” (Matthew 7:24–25, KJV)

The people of Valmeyer moved their homes to high, solid ground. Jesus teaches that a life is like a house: built on His words, it stands when the floods of trouble come.

Practice answers

1. Build on high ground; raise the house up (stilts or a high foundation); seal it so water cannot get in; let water pass through safely with flood vents and water-resistant materials.
2. The people voted to move the whole town and rebuilt it on high bluffs above the river valley.
3. No. A 100-year flood has a 1 in 100 chance of happening every single year. Having one last year does not change the chance this year, so it could happen again soon.
4. Water pushes up on things in it (buoyancy). A house that is not anchored can float off its foundation and be carried away.
5. 8 + 11 + 5 = 24; 24 ÷ 3 = 8 mL.
6. (a) Design 3. (b) Its floor was right at the water level (4 cm), so water touched and seeped in, especially with small waves. (c) The taller the stilts, the less water got inside; once the floor was above the water, it stayed dry.

7. Change: vents (holes in the lower walls) or no vents. Keep the same: box size and material, anchoring, water depth, the size and speed of the wave. Measure: whether each house tips or slides, or how far it moves. The control is the house without vents.
8. Raise it on piers, if the floor ends up above the flood level. Sealing works only for shallow water; water 1 meter deep pushes very hard on walls and can leak in or break them. A raised floor lets water flow underneath without touching the living space. A wise builder would add a little extra height for safety.

Unit 6 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) Name two reasons the South Fork Dam failed on May 31, 1889.
2. (5 pts) A flood wave travels 23 kilometers in 1 hour. How far would it travel in 3 hours at the same speed? Could a person running at 10 kilometers per hour stay ahead of it?
3. (5 pts) What does the safety rule “Turn Around, Don’t Drown” mean, and why is it important?
4. (5 pts) What is a levee? Give one way a levee helps and one way it can go wrong.
5. (5 pts) A river is 7.4 meters deep. The levee top is 9 meters high. The river is rising 20 centimeters per hour. How much room is left, and how many hours until the water reaches the top?
6. (5 pts) Name three jobs a large dam such as Hoover Dam does, and tell why engineers after 1927 added floodways as well as levees.
7. (5 pts) Define watershed, divide and tributary.
8. (5 pts) One centimeter of rain on 1 square meter is 10 liters. How many liters of rain fall on a 20-square-meter driveway in a 2-centimeter storm? Would more of it run off than from a lawn of the same size? Why?
9. (5 pts) You want to test whether bare soil or grass makes more runoff. What do you change, what two things do you keep the same, and what do you measure?
10. (5 pts) (a) What does “100-year flood” mean? (b) A model house let in 12 mL, 9 mL and 15 mL of water in three trials. What is the average? (c) Name two ways to make a real house flood-wise.

Unit project: my flood-wise valley

Build a model river valley in a large bin or on a sheet of plastic outdoors, using sand or soil. Shape hills with a clear divide, a main river with at least two tributaries, a dam with a spillway, a levee protecting a small town, and your best flood-proof model house from Lesson 6.4. Make it “rain” with a watering can and watch your valley handle the flood.

Beside the model, display your lab notebook with your data tables from the dam-break, levee and model-house tests and your bar graph. Write a paragraph that traces the path of the rain through your watershed and explains how each part of your design, the dam, the spillway, the levee and the house, helps keep people safe. Photograph or sketch the model before and after the rain.

- **Accuracy**: The model shows a correct divide, tributaries flowing downhill into a main river, a dam with a working spillway, a levee and a flood-wise house, all labeled.
- **Records**: Data tables from the unit’s experiments are complete, with units, three trials where needed, correct averages and a neat bar graph.

- **Explanation**: The paragraph correctly traces the water's path and explains how dams, spillways, levees and house design reduce flood danger, including at least one weakness.
- **Care**: The model and notebook are neat, carefully built and clearly presented, with before-and-after sketches or photos.

Answer key

1. Any two: very heavy rain filled the lake faster than water could leave; the spillway was blocked by fish screens clogged with branches; the outlet pipes at the bottom had been removed, so the lake could not be lowered; the top of the dam had been lowered for a road; the sagging middle had been poorly patched. The water went over the top and washed the earthen dam away.
2. 23 × 3 = 69 kilometers. No: the flood moves at 23 km per hour, more than twice as fast as the runner. The safe choice is to climb to high ground right away.
3. Never walk, play or drive into flood water; turn back and find another way. Just 15 cm (6 in) of fast water can knock a person down, and about 30 cm (12 in) can carry away most cars.
4. A levee is a long wall or bank of earth along a river that keeps flood water in the channel. Helps: keeps towns and farms behind it dry. Can go wrong: it squeezes the river so the water rises higher, and if it breaks or is overtopped, water rushes out all at once.
5. 9 − 7.4 = 1.6 m = 160 cm of room. 160 ÷ 20 = 8 hours.
6. Any three: holds back floods, stores water for cities, stores water for farms, makes hydroelectric power, makes a lake for recreation. Floodways give extra water a safe place to go, so the river drops and the levees do not have to hold back as much.
7. Watershed: all the land that drains to one river, lake or bay. Divide: the high ground that separates one watershed from another. Tributary: a smaller stream or river that flows into a larger one.
8. 2 × 10 = 20 liters per square meter; 20 × 20 = 400 liters. Yes, more runs off the driveway, because the hard surface lets almost no water soak in, while lawn soil soaks up much of it.
9. Change: the surface (bare soil or grass). Keep the same (any two): the slope, the tray size, the amount of water, how fast it is poured, how wet the soil starts. Measure: the amount of water that runs off.
10. (a) A flood that has a 1 in 100 chance of happening in any single year; it can happen in back-to-back years. (b) 12 + 9 + 15 = 36; 36 ÷ 3 = 12 mL. (c) Any two: build on high ground; raise it on stilts or a high foundation; seal it against shallow water; add flood vents and water-resistant materials; anchor it firmly to the foundation; move the furnace and electrical boxes up high.

UNIT 7

Oceans

Most of the water on God's earth is in the sea, and the sea is not still. In this unit you will learn that the oceans have **paths**: belts of steady wind, great loops of moving water called currents, and slow, deep streams creeping along the ocean floor. The Bible speaks of "whatsoever passeth through the paths of the seas" (Psalm 8:8), and the scientists you will meet spent their lives finding those paths.

You will sit at Matthew Fontaine Maury's desk among thousands of old ship logbooks and see how he turned them into charts that cut weeks off long voyages. You will follow 28,800 bath toys that fell into the North Pacific in a storm, sail with the floating laboratory HMS *Challenger* as her scientists bottled seawater from around the world, and listen as a Nantucket whaling captain explains the Gulf Stream to Benjamin Franklin. Along the way you will keep a wind logbook, make a wind-driven current, float an egg in salt water and hunt for a warm current with a thermometer.

BEFORE YOU BEGIN

- Can read a thermometer in °C and °F
- Knows the four main compass directions and can find north with a compass
- Can multiply and divide whole numbers to find a total or an average
- Knows how water evaporates and condenses in the water cycle (Unit 1)

MASTERY CHECKLIST

- I can tell how Matthew Fontaine Maury used ship logbooks to chart the winds and currents of the sea.
- I can explain what drives surface currents and why they form great loops called gyres.
- I can tell the difference between a wave and a current.
- I can explain salinity and density and why cold, salty water sinks to make deep currents.
- I can trace the path of the Gulf Stream and tell how Franklin and Folger charted it.
- I can plan a fair experiment by changing one thing and keeping the others the same.

OPTIONAL BOOKS AND RESOURCES

- **NOAA Ocean Service Education** (https://oceanservice.noaa.gov/education/): Free. Short articles, tutorials and pictures about ocean currents, salinity and the Gulf Stream from the National Oceanic and Atmospheric Administration. Parents can choose pages to read aloud.
- **NOAA SciJinks** (https://scijinks.gov/): Free. Kid-friendly pages, games and pictures about weather, satellites and the ocean, from NOAA and NASA.
- **NASA Scientific Visualization Studio: Perpetual Ocean** (https://svs.gsfc.nasa.gov/3827): Free. A beautiful animated map that shows the

ocean’s surface currents swirling around the world, made from real data. Look for the Gulf Stream along the east coast of North America.

7.1 Matthew Fontaine Maury and the "Paths of the Seas" (Psalm 8:8) ★

OBJECTIVES

- Tell how Matthew Fontaine Maury used thousands of old ship logbooks to make wind and current charts of the oceans.
- Explain that one observation is only a clue, but many careful observations together can show a pattern, such as the steady trade winds.
- Keep a wind logbook, tally the wind directions and draw a bar graph that shows which way the wind blows most often.

Warm-up. Wet one finger and hold it up outside, or hold up a thin strip of tissue paper. Which side of your finger feels cool, or which way does the tissue blow? Use the sun or a compass to decide which direction the wind is coming *from*. Write it down with the date and time. Do you think the wind will come from the same direction tomorrow? How could you find out?

Video. Coming soon. Matthew Fontaine Maury, Pathfinder of the Seas, ship logbooks, wind and current charts, and the trade winds and doldrums: search NOAA, NOAA Ocean Service, the U.S. Naval Observatory, Smithsonian, NOAA SciJinks, Homeschool Pop (Alternate), Moody Science classics and short history-of-navigation documentaries.

KEY TERMS

logbook
A daily record kept on a ship that tells where the ship was, which way the wind blew, the weather and how the water moved the ship.

data
Facts and measurements that are collected and written down so they can be studied.

pattern
Something that happens again and again in the same way, so you can expect it to happen next time.

ocean current
A steady stream of water that moves through the ocean in a certain direction, like a river in the sea.

trade winds
Steady winds near the equator. North of the equator they blow from the northeast; south of the equator they blow from the southeast.

doldrums
A belt of light, shifting winds and calms near the equator, where sailing ships could sit still for days.

CORE IDEAS

The story. In 1839 a young U.S. Navy officer named Matthew Fontaine Maury was riding a stagecoach in Ohio when it tipped over. His leg was badly hurt, and he could no longer serve at sea. A few years later, in 1842, the Navy put him in charge of its Depot of Charts and Instruments in Washington, D.C. There Maury found what most people thought was junk: stacks of old ship **logbooks**. Every day at sea, a ship's officers wrote down where the ship was, which way the wind blew, how strong it was and how the water carried the ship along. Thousands of voyages sat on dusty shelves, and no one had ever put them together.

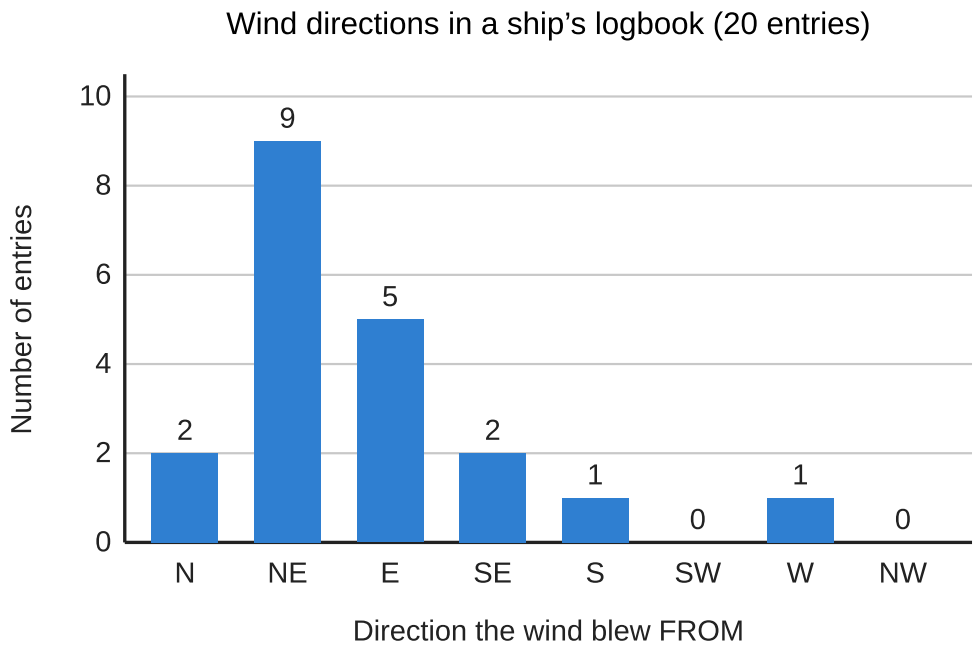
How he figured it out. Maury and his helpers copied the numbers from the logbooks onto charts, one small square of ocean at a time, month by month. When many ships crossing the same square in the same month all reported the same kind of wind and current, Maury knew it was a **pattern**, not luck. In 1847 he published his first Wind and Current Chart of the North Atlantic. He gave his charts free to any captain who promised to keep a careful log on Maury's form and send it back. Soon ships all over the world were collecting **data** for him. Captains who followed his routes cut weeks off long voyages. In 1853 he helped bring navy officers from many nations together in Brussels, Belgium, where they agreed to keep the same kind of logbook. Sailors began calling him the "Pathfinder of the Seas."

Paths in the sea. A story often told about Maury says that once, when he was sick in bed, he asked to have the Bible read to him and heard Psalm 8:8: "whatsoever passeth through the paths of the seas." If God's Word said the seas have paths, he reasoned, then he would find them. We cannot check every detail of that story, but we do know that Maury believed the ocean was ordered by its Maker, and in his book *The Physical Geography of the Sea* (1855) he wrote about the winds and waters as God's works.

The big idea. One observation is only a clue. Thousands of observations, sorted carefully, show a pattern. Maury's charts showed that the winds over the ocean blow in great belts. Near the equator the **trade winds** blow steadily from the northeast (north of the equator) and from the southeast (south of it). Right at the equator lie the **doldrums**, where winds are light and a sailing ship could drift for days. His charts also showed **ocean currents**, streams of water that move in the same direction year after year. A wise captain used the steady winds and currents to help him and steered around the calms.

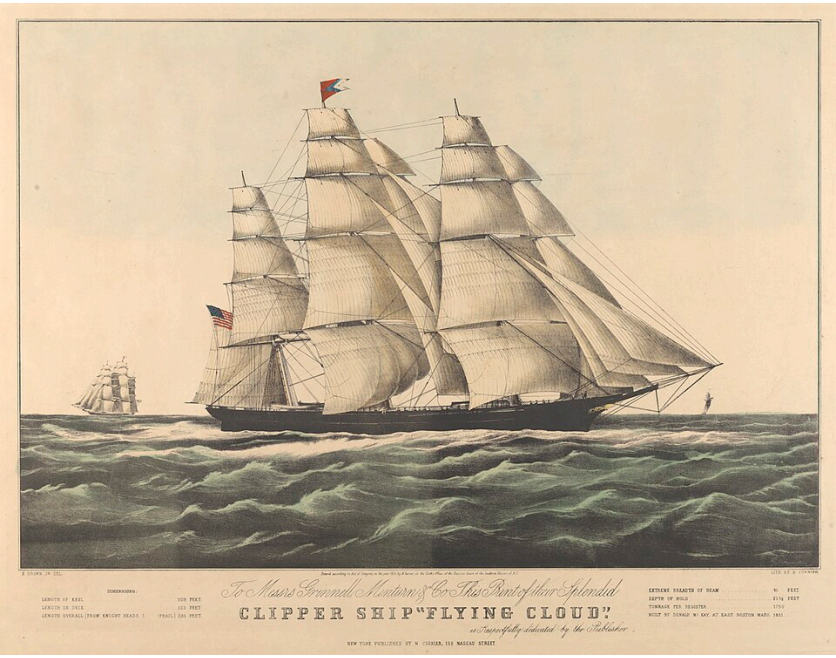
In the world today. Ships, floating buoys and satellites still report wind and water every day, and nations still share their data, just as Maury hoped. The pilot charts sailors use today grew out of his work. When you write down the wind and weather in your own notebook, you are doing the same kind of science: watching carefully, recording honestly and looking for the pattern.

God's handiwork. Psalm 8 says that God made man "to have dominion over the works of thy hands" (Psalm 8:6), including the fish of the sea and whatever passes through its paths. The sea is not a jumble. It has paths, belts of wind and steady currents that a patient observer can learn. Maury, with his injured leg, served sailors around the world from a desk full of old logbooks.



Wind directions from 20 logbook entries made near 15° north of the equator in winter (practice data). Most entries say the wind blew from the northeast: the trade winds.

PICTURE STUDY



Clipper Ship “Flying Cloud”, E. Brown Jr. (artist), published by Nathaniel Currier, 1852 · Hand-colored lithograph · National Maritime Museum, Greenwich, England; other copies are held in the Library of Congress, Washington, D.C.

The *Flying Cloud* was a clipper ship built in East Boston by Donald McKay and launched in 1851. Clippers were long, narrow ships made for speed. On her first voyage, from New York around Cape Horn to San Francisco, she was navigated by Eleanor Creesy, the captain’s

wife, who had studied Maury's wind and current charts. The ship arrived in 89 days and 21 hours, a record that amazed the world.

Nathaniel Currier's print shop in New York sold inexpensive colored pictures of famous ships, trains and events, so families all over America could hang them on their walls.

Look closely

- Count the masts. How many sails can you find on the front mast alone?
- Look at the sails and flags. Which way is the wind blowing? How can you tell?
- Look at the shape of the hull (the body of the ship). Why would a long, narrow ship be fast?
- Find the water. Are there waves? What does the sea look like near the front of the ship?

Talk about it

1. A clipper had no engine. What did its navigator need to know to make a fast voyage?
2. How did the logbooks of hundreds of slower ships help the *Flying Cloud* set a record?
3. If you were navigating this ship, would you rather have a fast ship or a good chart? Why?

> **Safety first.** Ask an adult to help push the pin through the straw and to handle the scissors. Set up your wind vane on the ground or a low post. Never climb onto a roof or railing to measure wind.

EXPERIMENT: KEEP A MAURY LOGBOOK: WHICH WAY DOES OUR WIND BLOW?

Maury found the paths of the winds by reading thousands of logbook entries. You will build a simple wind vane, keep your own logbook for one week, and look for a pattern in your data.

You will need

- A plastic drinking straw
- An index card or a piece of a cereal box
- A straight pin
- A new pencil with an eraser on the end
- A paper cup turned upside down, with a lump of clay or a few stones taped inside to hold it down (or a flowerpot of soil)
- A compass or a compass app, and a marker
- Scissors, tape, a ruler and your science notebook

Steps

1. **Question:** From which direction does the wind blow most often at our house this week? Write your **prediction**.
2. Cut a small triangle (the arrowhead) and a bigger square (the tail) from the card. Cut a short slit in each end of the straw and slide the arrowhead into one end and the tail

into the other.
3. Push the pencil, point down, through the bottom of the cup so the eraser sticks up. With an adult's help, push the pin through the middle of the straw and into the eraser. Blow on the vane to make sure it spins freely.
4. Use the compass to find north. Set the cup outside in an open place and mark N, E, S and W on the cup with the marker, lined up with the compass.
5. Twice a day for 7 days, at the same two times, look at the vane. The arrowhead points to the direction the wind is coming **from**. Record in a table: Date, Time, Wind from, Wind strength (calm, light, strong), Sky.
6. At the end of the week, make a tally of the wind directions and draw a bar graph like the one in this lesson.
7. Write two sentences: Which direction was most common? Was one week enough to call it a pattern, or would Maury want more data?

Tips

- **What we keep the same:** the same place, the same vane, the same two times each day. **What we measure:** the direction the wind comes from. Keeping things the same makes your records fair to compare.
- Winds are named for the direction they come *from*. A north wind blows from the north toward the south.
- If the vane points a different way every few seconds, wait one minute and write down the direction it points most of the time.

Check your work

- I built a wind vane that turns freely and is lined up with north.
- I kept 14 honest logbook entries and made a tally and bar graph.
- I can explain how Maury turned old logbooks into charts of the winds and currents.

FIELD NOTEBOOK

1. Copy the first page of your wind logbook neatly, with columns for Date, Time, Wind from, Wind strength and Sky, the way a ship's officer would.
2. Draw a globe and color three belts: the trade winds north of the equator (arrows from the northeast), the doldrums at the equator (write "calm"), and the trade winds south of the equator (arrows from the southeast).
3. Write Psalm 8:8 in your best handwriting and draw a sailing ship following a dotted "path" across the sea beneath it.

> **From history.** Before his injury, Maury had sailed around the world. As a young midshipman he served aboard the USS *Vincennes*, which from 1826 to 1830 became the first U.S. Navy ship to sail all the way around the globe. On long voyages he studied mathematics and navigation, and in 1836 he published a textbook on navigation for young officers. His years at sea taught him how much sailors needed better charts.

WORKED EXAMPLES

Example 1. A ship sailing near 15° north of the equator in winter made 20 logbook entries about the wind. The tally was: north 2, northeast 9, east 5, southeast 2, south 1, southwest 0, west 1, northwest 0. Which direction did the wind come from most often? How many entries came from the northeast or the east together? What pattern does this show?

(Use the map or drawing "The tallest bar shows the most common wind direction." shown earlier in this lesson.)

1. Look for the biggest number in the tally: northeast has 9, the most. On the bar graph it is the tallest bar.
2. Add northeast and east: 9 + 5 = 14 entries.
3. Check the total: 2 + 9 + 5 + 2 + 1 + 0 + 1 + 0 = 20. All entries are counted.
4. 14 out of 20 entries came from the northeast or east. That is more than half (half of 20 is 10).

Answer: The wind came from the northeast most often (9 of 20 entries), and 14 of 20 came from the northeast or east. This is the pattern of the northeast trade winds, which Maury found in thousands of logbooks.

Example 2. A sailing ship on its old route must travel 12,500 km (about 7,770 miles) and averages 250 km (about 155 miles) a day. On a new route from Maury's chart, it travels 12,000 km (about 7,460 miles) but finds steadier winds and averages 300 km (about 186 miles) a day. How many days does each route take, and how many days does Maury's route save?

1. Days = distance ÷ distance per day.
2. Old route: 12,500 km ÷ 250 km per day = 50 days.
3. Maury's route: 12,000 km ÷ 300 km per day = 40 days.
4. Days saved: 50 − 40 = 10 days.

Answer: The old route takes 50 days and Maury's route takes 40 days, saving 10 days. Steadier winds can save time even when the distance is about the same.

PRACTICE

1. EASY Name three things a ship's officer wrote in the logbook every day.
2. EASY Your weather vane's arrowhead points to the west. Is this a west wind or an east wind? Which way is the air moving?
3. EASY What are the doldrums, and why did sailors of sailing ships dread them?
4. MEDIUM A captain wrote down how far the current pushed his ship east each day. Monday: 20 km. Tuesday: 24 km. Wednesday: 18 km. Thursday: 22 km. Friday: 16 km.

(a) On which day was the push strongest? (b) What was the total for the five days? (c) What was the average push per day?

5. MEDIUM A ship must sail 6,000 km (about 3,730 miles). On one route it averages 200 km a day. On a route with better winds it averages 250 km a day. How many days does each route take, and how many days are saved?
6. MEDIUM Maury gave his charts away free. What did he ask captains to give him in return, and why was that a good trade for both sides?
7. HARD Lily wonders whether the wind blows from a different direction on top of a hill than in her backyard. Plan her experiment. What will she change? What must she keep the same? What will she measure? Why should she take many readings?
8. CHALLENGE Explain in three or four sentences why one ship's logbook could not show Maury the paths of the sea, but thousands of logbooks could.

COMMON MISTAKES

- Thinking a wind is named for where it is going. Winds are named for where they come *from*: a north wind blows from the north.
- Thinking one day's observation proves a pattern. A pattern only shows up after many careful observations, which is why Maury gathered thousands of logbooks.
- Thinking the ocean's winds and waters move at random. They follow belts and paths that stay much the same from year to year, though storms can interrupt them for a while.

Make it a game · Captain's Compass. Mark N, E, S and W on four pieces of paper and place them on the walls of a room, using a compass. A parent calls out a wind, such as "A northeast trade wind!" The player must stand in the middle and point to the direction the wind comes FROM, then walk the way the wind would push a ship. Score a point for each correct move. If the parent calls "Doldrums!" everyone must freeze for ten seconds. Play to ten points.

Scripture. "The fowl of the air, and the fish of the sea, and whatsoever passeth through the paths of the seas." (Psalm 8:8, KJV)

David wrote that God gave people dominion over the creatures of the air and the sea. The sea has "paths," and Maury spent his life finding them so that sailors could travel more safely. Learning the order God built into the world is one way we care for our neighbors.

Practice answers

1. Any three of: where the ship was (its position), which way the wind blew, how strong the wind was, the weather, and which way and how far the water carried the ship.
2. It is a west wind. The arrowhead points to where the wind comes from, so the air is moving from the west toward the east.
3. The doldrums are a belt of light, shifting winds and calms near the equator. Sailing ships had no engines, so without wind they could sit still for days.

4. (a) Tuesday, 24 km. (b) 20 + 24 + 18 + 22 + 16 = 100 km. (c) 100 ÷ 5 = 20 km a day (about 12 miles a day).
5. 6,000 ÷ 200 = 30 days. 6,000 ÷ 250 = 24 days. The better route saves 30 − 24 = 6 days.
6. He asked them to keep a careful log on his form and send it back. The captains got charts that made their voyages faster and safer, and Maury got more data, which made the next charts even better.
7. Change: the place (backyard or hilltop). Keep the same: the same wind vane, the same height above the ground, readings taken at the same times on the same days, and north lined up the same way. Measure: the direction the wind comes from. Many readings show a pattern; one reading could be just a passing gust.
8. One logbook tells what the wind and water did on a few days along one ship’s track, and that might have been unusual weather. When thousands of ships crossed the same part of the ocean in the same month, Maury could see what usually happened there. If most of them found the same wind and current, it was a dependable pattern a captain could plan on. More careful data made the pattern clearer and more trustworthy.

7.2 Currents

OBJECTIVES

- Tell how bath toys lost in the North Pacific in 1992 helped oceanographer Curtis Ebbesmeyer and other scientists track ocean currents.
- Explain that steady winds push surface currents, that Earth’s spin and the continents bend them into great loops called gyres, and that a current is different from a wave.
- Measure how fast a current moves in a model and calculate drift speed in kilometers per day.

Warm-up. Fill a sink, bathtub or large bowl with water and float a small cork, bottle cap or plastic toy in the middle. Without touching the water, try to move the toy to one side using only your breath. Then put your hand in the water and push it gently in one direction. Which made the toy travel farther? Did the water itself move, or only the toy?

Video. Coming soon. Ocean surface currents, gyres and the 1992 rubber duck spill tracked by Curtis Ebbesmeyer, plus waves versus currents: search NOAA Ocean Service, NOAA SciJinks, NASA (Perpetual Ocean visualization), Smithsonian Ocean, SciShow Kids, Homeschool Pop (Alternate) and Science Max.

KEY TERMS

surface current
A current in the top part of the ocean, pushed along mostly by steady winds.

gyre
A huge loop of ocean currents that circles an ocean basin. Gyres turn clockwise north of the equator and counterclockwise south of it.

warm current
A current that carries warm water from near the equator toward the poles.

cold current
A current that carries cold water from near the poles toward the equator.

wave
A moving ripple of energy on the water. In a wave the water mostly goes up and down in place; in a current the water itself travels.

CORE IDEAS

The story. In January 1992 a cargo ship crossing the North Pacific Ocean ran into a fierce storm. Several big metal shipping containers broke loose and fell into the sea. One of them held 28,800 plastic bath toys: yellow ducks, blue turtles, red beavers and green frogs. The container broke open, and the little toys floated away. About ten months later, in November 1992, beachcombers began finding them on the shores of Alaska near the town of Sitka.

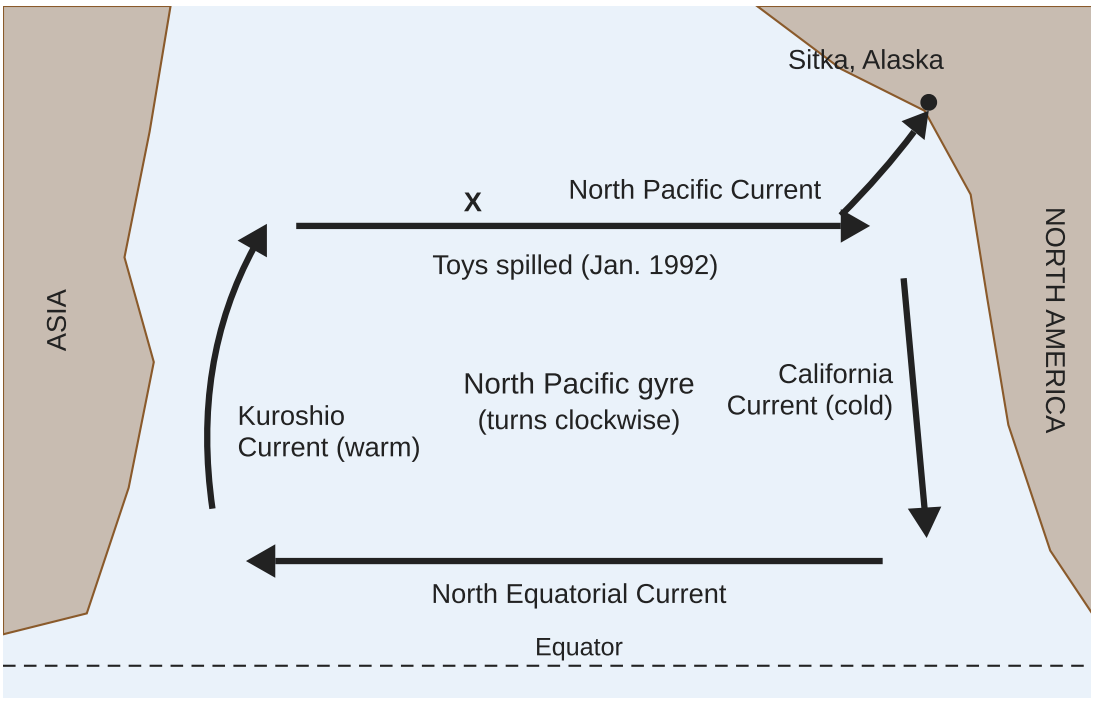
How they figured it out. An oceanographer in Seattle named Curtis Ebbesmeyer had already been tracking thousands of sneakers that spilled from another ship in 1990. When he heard about the toys, he asked beachcombers to report every one they found: where, when and what kind. With his friend Jim Ingraham, who worked with a computer model of North Pacific currents, he compared the real finds with the paths the model predicted. Each toy was like one of Maury's logbook entries: one data point. Together they showed the paths of the currents. Some toys were carried north toward Alaska, while others kept drifting for years around the North Pacific.

The big idea. An **ocean current** is a stream of water moving in a steady direction. Most **surface currents** are pushed by steady winds, like the trade winds and westerlies Maury charted. But currents do not go straight. Because Earth spins, moving water curves to the right north of the equator and to the left south of it. When the curving currents run into continents, they turn again. The result is giant loops called **gyres**. In the North Pacific and North Atlantic, the gyres turn clockwise. In the southern oceans they turn counterclockwise.

Warm and cold. A current that flows away from the equator carries warm water with it. That is a **warm current**, like the Kuroshio Current off Japan or the Gulf Stream off Florida. A current that flows from the cold north or south toward the equator is a **cold current**, like the California Current that keeps the water at California's beaches chilly even in summer. Deep in the ocean there are slow currents too, moved not by wind but by cold, salty water sinking. You will learn about those in the next lesson.

Waves are not currents. A **wave** carries energy across the water, but the water itself mostly bobs up and down in a little circle and stays in nearly the same place. Watch a floating leaf when a wave passes: it rises and falls but does not travel far. A current is different. In a current the water itself moves along, carrying leaves, logs, ducks and ships with it.

In the world today. Today scientists track currents with thousands of drifting buoys and floats that send their positions to satellites, and with satellites that measure the ocean surface. The Coast Guard uses current maps to search for people lost at sea, and ship captains still use currents to save time and fuel, just as Maury taught.



The North Pacific gyre turns clockwise. Toys spilled at the X were carried east by the North Pacific Current, and some turned north toward Alaska.

PICTURE STUDY



Under the Wave off Kanagawa (The Great Wave), Katsushika Hokusai, about 1831 · Color woodblock print · Prints are held in many museums, including the Metropolitan Museum of Art, New York

Katsushika Hokusai was a Japanese artist who made this print as part of a series called *Thirty-Six Views of Mount Fuji*. A woodblock print is made by carving a picture into blocks of wood, one block for each color, then inking the blocks and pressing paper onto them. Because many copies could be printed, this picture is now in museums all over the world.

Hokusai shows fishermen rowing fast boats home through a stormy sea. The great wave towers over them, and far away the sacred mountain of Japan looks tiny and calm.

Look closely

- Find Mount Fuji. Why do you think Hokusai made the mountain look so small?
- Count the boats. How are the rowers holding on?
- Look at the top of the wave. What does the foam look like to you?
- Find the smaller wave in the front. Does its shape remind you of anything in the background?

Talk about it

1. Is this a picture of a wave or a current? How can you tell the difference?
2. If the boats were caught in a current instead of under a wave, what would happen to them?
3. Why do you think people all over the world still love this picture?

> **Safety first.** Work over a towel or outdoors and wipe up spills right away so no one slips. Each person should use his or her own straw.

EXPERIMENT: WIND MAKES A CURRENT: DOES A STRONGER WIND MAKE A FASTER CURRENT?

Most surface currents are pushed by wind. You will make a small ocean in a pan, blow “wind” across it, and time how fast a floating marker travels. Then you will add a “continent” and watch your current turn.

You will need

- A large baking pan or shallow plastic storage bin
- Water (about 3 cm, or a little over 1 inch, deep)
- Paper hole-punch dots, small pieces of cork, or a few round cereal pieces (floating markers)
- A bendy straw for each person
- Masking tape, a ruler and a marker
- A stopwatch or clock with a second hand
- A brick, a heavy mug or a small water-filled container to be a continent
- Your science notebook

Steps

1. **Question:** Does a stronger wind make the current move faster? Write your **prediction**.
2. Fill the pan with water about 3 cm deep. Put tape on the side of the pan to mark a start line and a finish line 20 cm (about 8 inches) apart.

3. Set one floating marker at the start line. Hold the straw at the same spot each time, low and level with the water, about 5 cm behind the marker.
4. **Gentle wind:** Blow gently and steadily. Time how many seconds the marker takes to reach the finish line. Do 3 trials.
5. **Strong wind:** Blow harder but still steadily. Time 3 more trials.
6. Record a table with columns: Wind (gentle or strong), Trial, Seconds to go 20 cm. Find the average for each kind of wind.
7. **Add a continent:** Set the brick or mug in the pan near the far end. Sprinkle several markers on the water and blow steadily along one side. Watch how the current turns when it hits the “land.” Draw the path in your notebook.

Tips

- **What we change:** how hard we blow. **What we keep the same:** the water depth, the straw’s distance and angle, the same kind of marker and the same 20 cm distance. **What we measure:** seconds to travel 20 cm.
- Watch the markers that are not right in front of the straw. Does the water move only where you blow, or does it drag nearby water along too?
- Real ocean currents also curve because Earth spins. Your pan does not spin, so only the walls and the “continent” can turn your current.

Check your work

- I timed 3 trials for each kind of wind and found the averages.
- I saw my current turn when it reached the continent.
- I can explain the difference between a wave and a current.

FIELD NOTEBOOK

1. Draw the North Pacific gyre with its four currents and arrows going clockwise. Draw a little yellow duck at the spill and a dotted line showing its trip toward Alaska.
2. Draw a cork on a wave in two pictures: on the top of the wave and in the low part after it passes. Write one sentence explaining why the cork did not travel far.
3. Make a two-column chart called “Warm or Cold Current?” and list the Kuroshio Current, the Gulf Stream and the California Current in the right columns.

> **From history.** The toys were not Curtis Ebbesmeyer’s first floating clues. In May 1990 a ship lost containers holding about 61,000 Nike shoes in a North Pacific storm. Months later, the shoes began washing up on beaches in British Columbia, Washington and Oregon. Because each shoe had a serial number, Ebbesmeyer could find out which container it came from, and beachcombers helped him map where the shoes landed. The shoes and the toys taught people that a careful scientist can learn from almost anything, even a lost sneaker.

WORKED EXAMPLES

Example 1. Scientists drop a drifting bottle into a current. Twenty days later it is found 600 km (about 370 miles) away. On average, how far did it drift each day? At that speed, how many days would it take to drift 1,500 km (about 930 miles)?

1. Distance each day = total distance ÷ number of days.
2. 600 km ÷ 20 days = 30 km per day (about 18.5 miles per day).
3. Days needed = distance ÷ distance per day.
4. 1,500 km ÷ 30 km per day = 50 days.

Answer: The bottle drifted about 30 km (about 18.5 miles) a day. At that speed it would take 50 days to drift 1,500 km. Real currents speed up and slow down, so this is an average.

Example 2. This table shows typical surface-water temperatures in four currents (rounded). Kuroshio Current off southern Japan: 24°C (75°F). California Current off California: 14°C (57°F). Gulf Stream off Florida: 27°C (81°F). Labrador Current off Canada: 4°C (39°F). Which currents are warm currents and which are cold currents? How much warmer is the Gulf Stream than the Labrador Current?

1. Warm currents flow from near the equator. The Gulf Stream (27°C) and the Kuroshio (24°C) have the warmest water.
2. Cold currents flow from near the poles. The California Current (14°C) and the Labrador Current (4°C) have the coldest water.
3. Subtract: 27°C − 4°C = 23 degrees Celsius. In Fahrenheit: 81°F − 39°F = 42 degrees Fahrenheit.

Answer: The Gulf Stream and the Kuroshio are warm currents. The California Current and the Labrador Current are cold currents. The Gulf Stream is about 23°C (42°F) warmer than the Labrador Current.

PRACTICE

1. EASY What pushes most surface currents along?
2. EASY Which way do the great gyres turn in the North Atlantic and North Pacific: clockwise or counterclockwise? Which way do they turn south of the equator?
3. EASY A ball floats in the ocean. A wave passes under it. Does the ball travel far with the wave? What would happen if the ball were in a current instead?
4. MEDIUM A plastic duck drifts 15 km (about 9 miles) a day. How far will it drift in 30 days? In 60 days?
5. MEDIUM A beachcombing club made this practice table of toys found on one beach. Month 9 after the spill: 0 toys. Month 10: 12 toys. Month 11: 20 toys. Month 12: 9 toys.

Month 13: 4 toys. (a) In which month were the most toys found? (b) How many toys were found in all? (c) If you drew a bar graph, which bar would be shortest?

6. MEDIUM Look at the North Pacific gyre map. A toy falls into the sea at the X. Which current carries it first, and in which direction? If it turns south near North America instead of north, which current is it in now?
7. HARD Ben wants to find out whether the depth of the water in his pan changes how fast a wind-driven current moves a floating marker. Plan his experiment: what he will change, what he will keep the same, what he will measure and how he can make his results more trustworthy.
8. CHALLENGE In three or four sentences, explain how a spill of bath toys became useful to science.

COMMON MISTAKES

- Thinking waves carry water across the ocean. Waves carry energy; the water in a wave mostly bobs up and down. Currents are what carry water from place to place.
- Thinking currents flow in straight lines in the direction the wind blows. Earth’s spin bends them, and continents turn them, so they form great loops called gyres.
- Thinking all currents are on the surface. There are also slow, deep currents far below, moved by cold, salty water sinking.

Make it a game · Ride the Gyre. Lay four sheets of paper in a big square on the floor and label them Kuroshio Current, North Pacific Current, California Current and North Equatorial Current, placed like the map. You are a rubber duck starting on the North Pacific Current. A parent rolls a die: move that many sheets clockwise around the gyre, saying the name of each current you pass and whether it is warm or cold. Roll a 6 and you may turn north to “Sitka, Alaska” and wash ashore to win, but only if you can explain the difference between a wave and a current.

Scripture. “The LORD on high is mightier than the noise of many waters, yea, than the mighty waves of the sea.” (Psalm 93:4, KJV)

The sea is huge and strong. A single storm can toss shipping containers overboard, and its currents can carry things across an ocean. Yet the Lord who made the waters is mightier still, and the paths the waters follow are part of the order He gave them.

Practice answers

1. Steady winds, such as the trade winds and the westerlies.
2. Clockwise in the northern oceans and counterclockwise in the southern oceans.
3. No. The ball mostly bobs up and down as the wave passes and stays in nearly the same place. In a current, the water itself moves, so the ball would be carried along.
4. 15 × 30 = 450 km (about 280 miles) in 30 days. 15 × 60 = 900 km (about 560 miles) in 60 days.
5. (a) Month 11, with 20 toys. (b) 0 + 12 + 20 + 9 + 4 = 45 toys. (c) The month 9 bar, which would have no height at all, because 0 toys were found.

6. First the North Pacific Current carries it east. If it turns south along North America, it is in the California Current, a cold current.
7. Change: the water depth (for example 2 cm, 4 cm and 6 cm). Keep the same: the same pan, the same straw held at the same distance and angle, the same blowing strength (or the same small fan setting), the same kind of marker and the same distance to travel. Measure: the seconds the marker takes to go 20 cm. Do at least 3 trials at each depth and average them.
8. The toys floated and were easy to recognize, so every one found on a beach was a clue about where the currents had carried it. Curtis Ebbesmeyer asked beachcombers to report where and when they found toys. He and Jim Ingraham compared these reports with the paths a computer model of the currents predicted. The real finds helped them test and improve their understanding of how the North Pacific currents move.

7.3 Salt and Density

OBJECTIVES

- Tell how the scientists of HMS *Challenger* collected seawater from around the world and how chemist William Dittmar found that the mix of salts is nearly the same in every ocean.
- Explain salinity and density, and tell why salt water and cold water sink below fresh water and warm water.
- Test how much salt it takes to float an egg, changing one variable and keeping the others the same.

Warm-up. Fill two clear glasses with the same amount of water. Stir 3 spoonfuls of salt into one glass until you cannot see the salt anymore. Ask someone to mix up the glasses while you look away. Can you tell which one has salt just by looking? Think of a way to tell without tasting. (Hint: what happens if you set a few drops of each on a dark plate in a sunny window for a day?)

Video. Coming soon. Why the sea is salty, salinity, density of salt water and fresh water, the floating egg experiment, and the HMS Challenger expedition: search NOAA Ocean Service, NOAA SciJinks, USGS Water Science School, Smithsonian Ocean, SciShow Kids, Homeschool Pop (Alternate), Science Max and Moody Science classics.

KEY TERMS

salinity
How much salt is dissolved in water. Ocean water has about 35 grams of salt in every kilogram of water.

dissolve
To mix into a liquid so completely that you can no longer see the pieces. The salt is still there.

density
How much matter (mass) is packed into a certain amount of space. Something denser than water sinks in it; something less dense floats.

deep current
A slow current far below the surface, made when cold, salty, dense water sinks and spreads along the ocean floor.

brackish water
Water that is a little salty, saltier than fresh water but less salty than the sea, as where a river meets the ocean.

CORE IDEAS

The story. On December 21, 1872, a British navy ship named HMS *Challenger* sailed out of Portsmouth, England. Most of her big guns had been taken out to make room for laboratories. For about three and a half years the scientists aboard sailed across every great ocean except the Arctic, about 127,000 km (79,000 miles) in all. Again and again they stopped, lowered weighted lines to measure how deep the sea was, took the water's temperature, and pulled up bottles of water from the surface and from far below. The ship came home in May 1876 with thousands of samples.

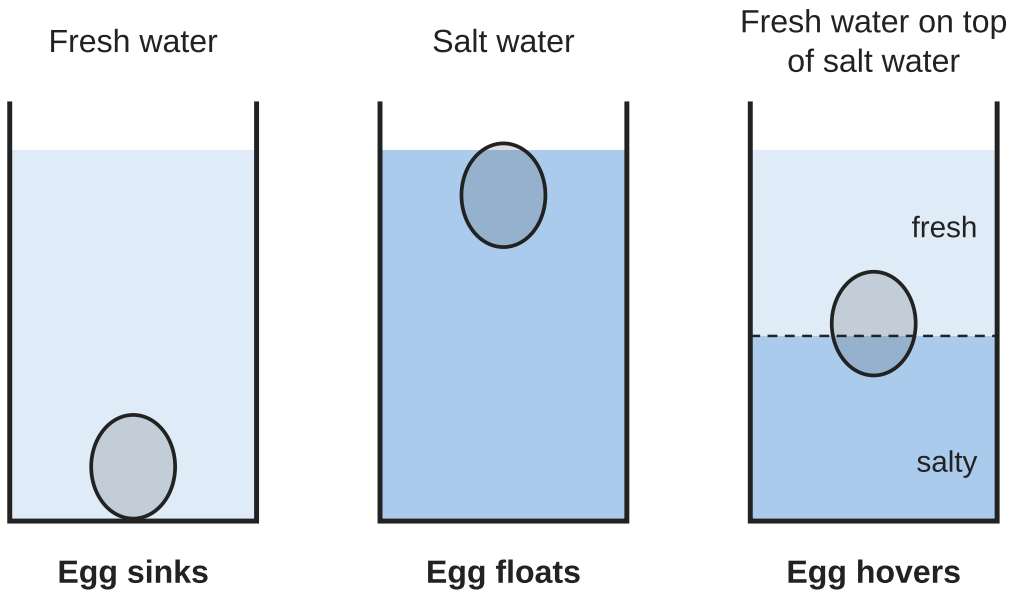
How they figured it out. Back in Scotland a careful chemist named William Dittmar tested 77 of the *Challenger*'s seawater samples, from many oceans and many depths. He found that some water was a little saltier than other water, but the *mix* of salts was nearly the same everywhere. By far the biggest part was sodium chloride, the same salt we put on food. His report, published in 1884, showed that all the oceans are really one connected sea, stirred together by its currents.

The big idea. Salinity tells how much salt is **dissolved** in water. Ocean water has about 35 grams of salt in each kilogram of water, about 2 tablespoons in a liter (about 1 quart). The salt comes mostly from rocks. Rain and rivers dissolve tiny bits of minerals from the land and carry them to the sea, and hot springs on the sea floor add more. When the sun evaporates seawater, only the water rises into the air. The salt stays behind. That is why rain is fresh even though the sea is salty.

Heavier for its size. Density tells how much matter is packed into a space. A liter of fresh water has a mass of about 1,000 grams. A liter of seawater has about 1,025 grams, because the dissolved salt adds mass. Salt water is denser, so it pushes up harder on things that float in it. That is why swimming in the ocean feels easier than swimming in a lake, and why people float like corks in the Dead Sea, which is about ten times saltier than the ocean. Cold water is denser than warm water too. Dense water sinks below less dense water.

The deep currents. Near Greenland and Antarctica, sea water gets very cold. When sea ice forms, most of the salt is left behind in the water below, making it even saltier. This cold, salty, dense water sinks all the way to the bottom and creeps slowly along the ocean floor toward the equator. These **deep currents** move much more slowly than surface currents, but they carry water through all the oceans.

God's handiwork. The salt in the sea is a gift. Because salt water freezes at about −2°C (about 28°F), colder than fresh water, the open ocean does not freeze as easily as a pond. When sea ice does form, it floats on top like a blanket and the creatures below keep swimming. The Lord asked Job, "Hast thou entered into the springs of the sea?" The *Challenger* scientists spent years only beginning to answer.



Denser water sinks below less dense water.

An egg sinks in fresh water, floats in salt water, and hovers in the middle when fresh water rests on top of denser salt water.

PICTURE STUDY



H.M.S. Challenger under sail passing icebergs, William Frederick Mitchell, 1880 · Colored print after a painting · National Maritime Museum, Greenwich, England

HMS *Challenger* was a wooden warship with both sails and a steam engine. For her great voyage she was turned into a floating laboratory, with rooms for studying chemistry and sea creatures, and with long lines and winches for reaching the deep sea floor. A few years after the voyage the English marine artist William Frederick Mitchell made this picture of her

sailing among icebergs, as she did in February 1874, when she became the first steamship to cross the Antarctic Circle. Mitchell drew her gunports open, though most of her guns had been taken out before she sailed.

When you look at this picture, remember that nearly everything the world knew about the deep ocean in the 1870s came from ships like this, one bottle of water and one measurement at a time.

Look closely

- Find the funnel for the steam engine. Why would a ship with sails also need an engine when it had to stop and hold still over one spot for hours?
- Count the masts and look at the sails. Many are rolled up (reefed). Is the ship in calm weather or rough weather?
- Find the icebergs. Near them the scientists measured some of the coldest water of the voyage. Why does cold, salty water sink?
- Imagine where the laboratories might be inside the ship. Where would you put them?

Talk about it

1. Why did the *Challenger* scientists need samples from so many different places and depths?
2. What would you want to measure if you were aboard the *Challenger*?
3. How is a sample of seawater like one entry in Maury's logbooks?

> **Safety first.** Raw eggs can carry germs: wash your hands with soap after handling the egg, and wipe up any spills. Do not drink the salt water. Use cool or warm tap water only, not hot water from the stove.

EXPERIMENT: HOW MUCH SALT FLOATS AN EGG?

An egg is a little denser than fresh water, so it sinks. Salt makes water denser. You will add salt one spoonful at a time to find out how much it takes to make the egg float. Then you will build a "sea" with two layers and make the egg hover in the middle.

You will need

- One raw egg in its shell
- A tall clear glass or jar that holds at least 600 mL (about 2½ cups)
- A measuring cup and 500 mL (about 2 cups) of tap water at room temperature
- Table salt (about 10 level tablespoons) and a measuring tablespoon
- A long spoon for stirring and a big spoon for lowering the egg
- A second glass, food coloring and a ruler
- Your science notebook

Steps

1. **Question:** How many level tablespoons of salt in 500 mL of water does it take to make an egg float? Write your **prediction**.
2. Pour 500 mL of room-temperature water into the tall glass. Gently lower the egg in with a spoon. Record what happens. Then lift the egg out.
3. Add 1 level tablespoon of salt. Stir until you cannot see any salt grains. Lower the egg in again and record: sinks, rises off the bottom, or floats at the top.
4. Keep adding 1 level tablespoon at a time, stirring well and testing the egg after each spoonful. Record each result in a table: Tablespoons of salt, What the egg did.
5. Stop when the egg floats at the top. Circle that number in your table.
6. **Two-layer sea:** Pour your salty water into the second glass until it is half full and add a few drops of food coloring. Very slowly pour fresh water over the back of a spoon so it lies on top without mixing. Gently lower the egg in. Measure with the ruler how far up the glass the egg stops.
7. Write two sentences: What did the salt do to the water? Why did the egg stop in the middle of the two-layer sea?

Tips

- **What we change:** the amount of salt. **What we keep the same:** the same egg, the same 500 mL of water, the same temperature, level spoonfuls and stirring until the salt dissolves. **What we measure:** whether the egg sinks or floats.
- Eggs are different. A very fresh egg is denser and may need 4 to 6 tablespoons, while an older egg may float with less. That is why we keep the same egg for every trial.
- The colored salt water stays on the bottom because it is denser. If the layers mix, the egg will sink lower; start over with a slower pour.

Check your work

- I added salt one spoonful at a time and recorded the result each time.
- I made a two-layer sea and measured where the egg stopped.
- I can explain why salt water is denser than fresh water.

FIELD NOTEBOOK

1. Draw the three glasses from this lesson: egg in fresh water, egg in salt water and egg in the two-layer sea. Label each with sinks, floats or hovers.
2. Draw a cross-section of the ocean near Greenland. Show sea ice on top, an arrow of cold, salty water sinking to the bottom, and an arrow creeping along the floor toward the equator.
3. Put a spoonful of salt water on a dark saucer and set it in a sunny window. Each day for three days, draw what you see. Write what was left behind.

> **From history.** Long before the *Challenger*, the English scientist Robert Boyle, a devout Christian who wrote often about God's wisdom in creation, published a small book in 1674 called *Observations and Experiments about the Saltness of the Sea*. He gathered

> reports from sailors and tested samples of seawater to see whether the sea was saltier in some places and depths than others. Boyle believed that careful experiments, not guesses, were the way to learn about God's world.

WORKED EXAMPLES

Example 1. Ocean water has about 35 grams of salt in every 1 kilogram of seawater. How much salt is in 4 kilograms of seawater? How many kilograms of seawater would you need to evaporate to collect 70 grams of salt?

1. Each kilogram holds 35 grams of salt.
2. 4 kilograms: 4 × 35 g = 140 grams of salt (about 5 ounces).
3. To collect 70 grams: 70 g ÷ 35 g per kilogram = 2 kilograms of seawater (about 4.4 pounds).

Answer: 4 kilograms of seawater hold about 140 grams of salt. You would need to evaporate about 2 kilograms of seawater to collect 70 grams of salt.

Example 2. Two jars each hold 500 mL of water. On a kitchen scale, the water in jar A has a mass of 500 grams and the water in jar B has a mass of 520 grams (practice data). Which water is denser? If you gently poured some of each into one glass, which would end up on the bottom? Which jar probably holds salt water?

(Use the map or drawing "Denser salt water sinks below fresh water and holds the egg up." shown earlier in this lesson.)

1. The jars hold the same amount (500 mL), so we can compare their masses directly.
2. Jar B packs 520 grams into the same space where jar A packs 500 grams. Jar B is denser.
3. Denser water sinks below less dense water, so water from jar B would end up on the bottom.
4. Dissolved salt adds mass without taking up much more space, so the denser water is probably the salt water.

Answer: Jar B is denser, would sink to the bottom, and is probably the salt water. Jar A is fresh water: 500 mL of fresh water has a mass of about 500 grams.

PRACTICE

1. EASY What does salinity measure?
2. EASY Where does most of the salt in the sea come from?
3. EASY The sea is salty, but rain is fresh. Why?
4. MEDIUM How much salt is in 5 kilograms of ocean water, if every kilogram holds about 35 grams?

5. MEDIUM This table shows about how many grams of salt are in each kilogram of water in five places. Lake Michigan: almost 0. Baltic Sea (middle): about 7. Open Atlantic Ocean: about 35. Red Sea: about 40. Dead Sea: about 340. (a) List the waters from least salty to most salty. (b) About how many times saltier is the Dead Sea than the open Atlantic? (c) Which one is brackish?
6. MEDIUM A ship is loaded in a freshwater river port and then sails out to sea. Will the ship ride a little higher or a little lower in the water at sea? Explain.
7. HARD Grace wants to know whether an ice cube melts faster in fresh water or in salt water. Plan her experiment. What will she change? What must she keep the same? What will she measure? What is her control?
8. CHALLENGE In three or four sentences, explain how freezing sea ice near Greenland helps start a deep current.

COMMON MISTAKES

- Thinking dissolved salt is gone because you cannot see it. The salt is still in the water, spread out into pieces too tiny to see. Evaporate the water and the salt appears again.
- Thinking heavy things always sink and light things always float. What matters is density: how much mass is packed into the space. A huge steel ship floats because its hollow shape takes up a lot of space.
- Thinking a thirsty sailor can drink seawater. Seawater is far too salty for the body and makes a person thirstier. Sailors must carry fresh water or make it by evaporating seawater and catching the steam.

> **Make it a game · Sink or Float?.** Fill a big bowl with fresh water and a second bowl with very salty water. Gather small things from the kitchen: a grape, a baby carrot, a cherry tomato, a cork, a coin, a small potato chunk. Before each test, every player guesses: sinks in fresh water? Sinks in salt water? Score a point for each right guess. Bonus point if you find something that sinks in the fresh water but floats in the salt water, and can explain why using the word “density.”

> **Scripture.** “Hast thou entered into the springs of the sea? or hast thou walked in the search of the depth?” (Job 38:16, KJV)

God asked Job questions no man of his time could answer. Many centuries later, the *Challenger* scientists lowered bottles and thermometers into the deep and found icy cold water near the floor of the sea. Later scientists found hot springs there too, and deep currents moving along the bottom. Every discovery shows how much more there is to learn about what God has made.

Practice answers

1. How much salt is dissolved in water.
2. From rocks on land. Rain and rivers dissolve tiny bits of minerals and carry them to the sea. Hot springs on the sea floor add some too.

3. When seawater evaporates, only the water rises into the air as water vapor. The salt is left behind in the sea, so the clouds and the rain that falls from them are fresh.
4. 5 × 35 = 175 grams of salt (about 6 ounces).
5. (a) Lake Michigan, Baltic Sea, Atlantic Ocean, Red Sea, Dead Sea. (b) 340 ÷ 35 is close to 10, so about 10 times saltier. (c) The Baltic Sea, which is a little salty but much less salty than the open ocean.
6. A little higher. Seawater is denser than fresh water, so it pushes up harder, and the ship does not have to sink as deep to be held up.
7. Change: the kind of water (fresh or salty). Keep the same: the same size of ice cube, the same kind of cup, the same amount of water at the same temperature, the same room and no stirring. Measure: the minutes until each ice cube is completely melted. The control is the cup of plain fresh water, set up the same way, to compare against. She should do more than one trial of each. (A surprise: the ice usually melts more slowly in the salt water, because the cold, fresh meltwater floats on top of the denser salt water and stays around the cube.)
8. Near Greenland the sea water becomes very cold, and cold water is denser than warm water. When sea ice forms, most of the salt is left in the water below, so that water becomes saltier and even denser. The cold, salty, dense water sinks to the ocean floor. Then it creeps slowly along the bottom toward the equator as a deep current.

7.4 The Gulf Stream

OBJECTIVES

- Tell how Benjamin Franklin and the Nantucket captain Timothy Folger charted the Gulf Stream to explain why mail ships from England were slow.
- Describe the path of the Gulf Stream and explain how this warm current affects ships, sea life and the weather of the lands it passes.
- Find a warm current with a thermometer by reading temperature data, and calculate how a current speeds up or slows down a ship.

Warm-up. Run a bathtub or a big sink of cool water. Ask a parent to slowly pour a cup of warm (not hot) water in at one end along the side. Close your eyes and slide your hand slowly across the water from one side to the other just below the surface. Can you feel where the warm "stream" is? Is it on the top or the bottom?

Video. Coming soon. The Gulf Stream, warm ocean currents seen from satellites, and Benjamin Franklin's Gulf Stream chart: search NOAA Ocean Service, NOAA SciJinks, NASA (sea surface temperature and Perpetual Ocean visualizations), Library of Congress, Smithsonian, Homeschool Pop (Alternate) and SciShow Kids.

KEY TERMS

Gulf Stream
A strong, fast, warm ocean current that flows out of the Gulf of Mexico, around Florida, north along the coast of the United States and then northeast across the Atlantic.

North Atlantic Current
The continuation of the Gulf Stream as it carries warm water across the Atlantic toward Europe.

packet ship
A ship that carried mail, and often passengers, on a regular schedule between two ports.

sea surface temperature
How warm or cold the water is at the top of the ocean. Warm currents show up as bands of warmer water.

head current
A current flowing against the direction a ship is trying to go, which slows the ship down.

CORE IDEAS

The story. Around 1769, Benjamin Franklin was living in London and serving as one of the deputy postmasters for Britain's American colonies. Customs officials in Boston sent a complaint to London about a puzzle, and the question came to Franklin. The mail ships, called **packet ships**, that sailed from Falmouth, England, to New York usually took about

two weeks longer than the merchant ships that sailed from London to Rhode Island, even though London was farther away. Why should the mail be so slow?

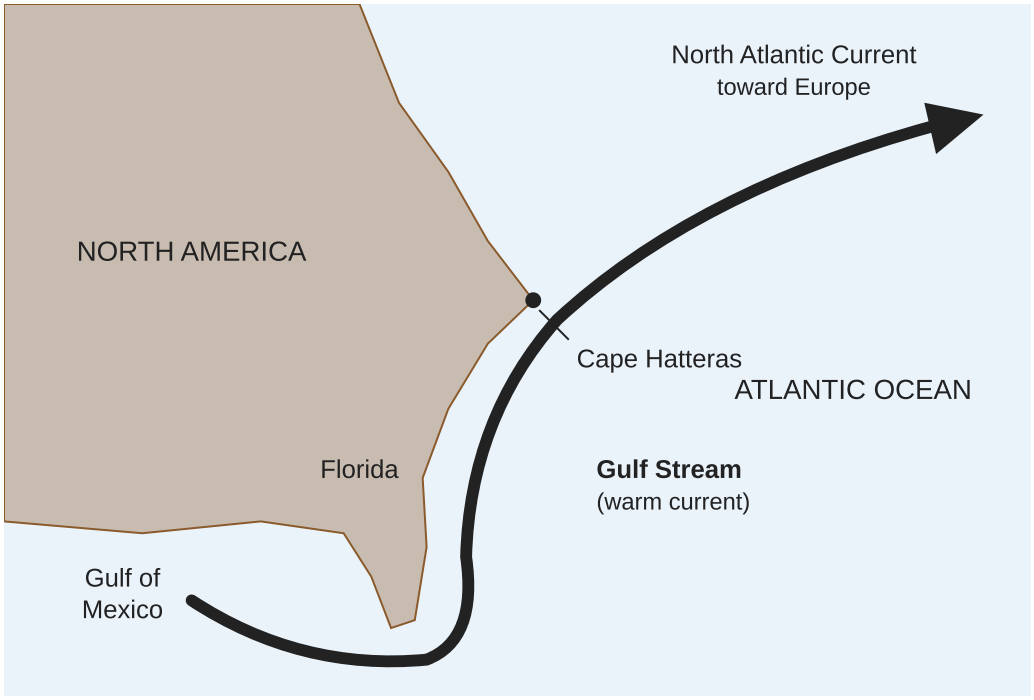
How they figured it out. Franklin asked his cousin Timothy Folger, a ship captain from the whaling island of Nantucket, who happened to be in London. Folger knew the answer at once. The Nantucket whalers hunted whales along the edges of a strong current that flowed from the Gulf of Mexico up the American coast and out across the Atlantic. The whalers sailed across it, not up against it. But the English packet captains sailed right into the middle of it and fought it for days. Folger said the whalers had even warned the packet captains, who would not take advice from American fishermen. Folger sketched the current's path, and Franklin had it printed as a chart for sailors. Later, on his voyages across the Atlantic, Franklin had buckets of seawater hauled aboard and measured them with a thermometer. He found that the water in the current was warmer than the sea around it. A thermometer could tell a captain when he had entered the stream.

The big idea. The **Gulf Stream** is one of the strongest currents in the world. It flows out of the Gulf of Mexico, around the tip of Florida and north along the coast of the United States. Near Cape Hatteras, North Carolina, it leaves the coast and swings northeast across the Atlantic. Farther east it is called the **North Atlantic Current**, and it carries warm water toward Europe. NOAA reports that the Gulf Stream is typically about 100 km (62 miles) wide and that near the surface its water can move as fast as about 2.5 meters a second (about 5.6 miles per hour), faster than you can walk. It carries more water than all the rivers of the world put together. Matthew Maury wrote of it, "There is a river in the ocean. In the severest droughts it never fails, and in the mightiest floods it never overflows."

Warm water, milder lands. The Gulf Stream is the western edge of the great North Atlantic gyre, which turns clockwise just like the North Pacific gyre in Lesson 7.2. It carries warm water from the tropics far to the north. That warm water warms the air above it. Together with the westerly winds, it helps make the winters of Ireland and Great Britain milder than the winters of places in Canada that are just as far north. Its warm waters also carry tropical fish and sea turtles far north of where you might expect them.

In the world today. Today satellites measure **sea surface temperature** every day. On their colored maps, the Gulf Stream shows up as a long, winding ribbon of warm water, just where Franklin and Folger drew it. Ship captains still ride the stream when heading northeast and stay out of it when heading southwest. Weather forecasters watch it too, because its warm water can strengthen storms that pass over it.

God's handiwork. The psalmist wrote that sailors who "go down to the sea in ships" see the wonders of the Lord in the deep. A whaling captain who had sailed the stream for years knew what learned men in London did not. Careful observation, from anyone, honors the God who made the paths of the seas.



The Gulf Stream flows out of the Gulf of Mexico, around Florida, up the coast to Cape Hatteras, and then across the Atlantic toward Europe as the North Atlantic Current.

PICTURE STUDY



The Gulf Stream, Winslow Homer, 1899 · Oil on canvas · The Metropolitan Museum of Art, New York

Winslow Homer was an American painter who loved the sea. In his later years he traveled in winter to Florida and the Bahamas, where he sailed across the warm, blue waters of the Gulf Stream and made many watercolor sketches. Back in his studio in Maine, he painted this large picture of a sailor whose small boat has lost its mast and is drifting helplessly in the stream.

Homer leaves the ending of the story to us. The sea around the boat is full of danger, but far away on the horizon there is a ship. Will it see him?

Look closely

- Find the broken mast. What do you think happened to this boat?
- Count the sharks. Where is the sailor looking?
- Find the waterspout. What kind of weather does it tell you about?
- Look closely at the horizon. What might give the sailor hope?

Talk about it

1. The boat has no sail. Where will the Gulf Stream carry it?
2. How does Homer make you feel that the sailor is in danger? How does he give a little hope?
3. Psalm 107 says sailors “see the works of the LORD, and his wonders in the deep.” What wonders and dangers of the deep do you see in this painting?

> **Safety first.** Use warm tap water that feels comfortable on your hand, never boiling water or water from the stove. Use a digital or plastic kitchen thermometer if you can; if it is glass, handle it gently. Wipe up spills so no one slips.

EXPERIMENT: FIND THE WARM STREAM, LIKE FRANKLIN

Franklin found the Gulf Stream with a thermometer. You will make a small “ocean” with a warm current running along one side, then measure the water at five places to find the stream, just as he did.

You will need

- A large clear plastic storage bin or a bathtub
- Cool tap water
- A pitcher of warm tap water with a few drops of red food coloring
- A kitchen or aquarium thermometer (digital is best)
- A large spoon, masking tape, a ruler and a marker
- A timer and your science notebook

Steps

1. **Question:** Where is the water warmest after a warm current flows in, and does the warm water stay on top or sink? Write your **prediction**.
2. Fill the bin about two-thirds full of cool water. Let it sit for 5 minutes to become still. Put tape along one long side and mark five spots, A to E, evenly spaced across the bin from the near side (A) to the far side (E).
3. Measure the starting temperature at spot C, holding the thermometer 2 cm (about 1 inch) below the surface for 30 seconds. Record it.

4. Slowly pour the warm colored water over the back of the spoon at one end of the bin, right along the A side, so it flows gently along that side like a current along a coast.
5. Wait 1 minute. Then measure at each spot, A to E, always 2 cm below the surface and always for 30 seconds. Record each temperature in a table: Spot, Temperature (°C or °F).
6. Now measure at spot A again, but this time near the bottom of the bin. Compare it with the surface reading at spot A.
7. Draw a bar graph of your five surface temperatures. Write two sentences: Where was the warm “stream”? Did the warm water stay on top or sink, and why?

Tips

- **What we change:** where we measure. **What we keep the same:** the depth of the thermometer, 30 seconds for each reading and the same thermometer. **What we measure:** the water temperature.
- The warm colored water will slowly spread and mix, so take your readings quickly and in the same order each time.
- Warm water is less dense than cool water, so it tends to stay near the top. The real Gulf Stream is a warm current near the surface, flowing over colder, denser water below.

Check your work

- I measured the temperature at five spots in the same careful way.
- I found the warm “stream” from my data and showed it on a bar graph.
- I can tell the story of Franklin, Folger and the slow mail ships.

FIELD NOTEBOOK

1. Draw a map of the eastern coast of North America and trace the Gulf Stream in red from the Gulf of Mexico to Cape Hatteras and out across the Atlantic. Label Florida, Cape Hatteras and the North Atlantic Current.
2. Draw two ships: a packet ship sailing west right into the Gulf Stream, and a whaler crossing it. Add arrows for the current and write which ship will be slower.
3. Copy Maury’s words, “There is a river in the ocean,” and under them write three ways the Gulf Stream is like a river and one way it is different.

> **From history.** The Gulf Stream was first written about by Spanish sailors. In April 1513, the explorer Juan Ponce de León was sailing along the east coast of Florida when his ships were pushed backward by a current so strong that it beat even a good wind. His pilot, Antón de Alaminos, remembered it. A few years later he used the current to carry a ship quickly from the Americas back toward Spain. After that, Spanish fleets sailing home rode the Gulf Stream north along Florida before turning east across the Atlantic.

WORKED EXAMPLES

Example 1. A captain sailing east from the American coast measures the water every 4 hours (practice data). Reading 1: 15°C (59°F). Reading 2: 16°C (61°F). Reading 3: 23°C (73°F). Reading 4: 24°C (75°F). Reading 5: 23°C (73°F). Reading 6: 16°C (61°F). Between which readings did the ship enter the Gulf Stream, and between which did it leave? How big was the jump in temperature when it entered?

1. Look for a big jump up. From reading 2 (16°C) to reading 3 (23°C) the water warms suddenly.
2. The warm readings (23°C, 24°C, 23°C) are readings 3, 4 and 5. The ship was in the warm current then.
3. Look for a big drop. From reading 5 (23°C) to reading 6 (16°C) the water cools suddenly.
4. Size of the jump: 23°C − 16°C = 7 degrees Celsius (73°F − 61°F = 12 degrees Fahrenheit).

Answer: The ship entered the Gulf Stream between readings 2 and 3 and left it between readings 5 and 6. The water warmed by about 7°C (12°F) when it entered, just the kind of change Franklin used to find the stream.

Example 2. A ship can move 10 km (about 6 miles) each hour through calm water. It meets a part of the Gulf Stream flowing 5 km (about 3 miles) per hour. How far does the ship travel in one hour if it sails with the current? Against the current? How far does each go in a whole day of 24 hours?

(Use the map or drawing "Ships sailing northeast can ride the stream; ships sailing southwest into it are" shown earlier in this lesson.)

1. With the current, the current adds to the ship's speed: 10 + 5 = 15 km per hour.
2. Against the current, the current takes away from the ship's speed: 10 − 5 = 5 km per hour.
3. In 24 hours with the current: 15 × 24 = 360 km (about 224 miles).
4. In 24 hours against the current: 5 × 24 = 120 km (about 75 miles).
5. Difference: 360 − 120 = 240 km in one day.

Answer: With the current the ship goes 15 km an hour, or 360 km a day. Against it, the ship goes only 5 km an hour, or 120 km a day. That is why the packet ships fighting the stream took weeks longer.

PRACTICE

1. EASY Where does the Gulf Stream begin, and in which direction does it flow along the coast of the United States?

2. EASY Who explained the Gulf Stream to Benjamin Franklin, and how did that person know about it?
3. EASY Is the Gulf Stream a warm current or a cold current? How can you tell from its path?
4. MEDIUM A ship moves 12 km an hour through calm water. The current is 4 km an hour. How fast does it go with the current? Against it? How long would it take to go 48 km against the current?
5. MEDIUM A student measured water temperatures across a model ocean (practice data). Spot A: 31°C. Spot B: 27°C. Spot C: 22°C. Spot D: 21°C. Spot E: 21°C. (a) Where is the warm current? (b) How much warmer is spot A than spot E? (c) On a bar graph, which bars would be the same height?
6. MEDIUM Why did the packet ships from Falmouth take about two weeks longer than merchant ships whose captains knew about the Gulf Stream?
7. HARD Noah wants to test whether warm water floats on top of cold water. He has a clear bin of cold water, red food coloring, warm water and room-temperature water. Plan his experiment. What will he change? What is his control? What will he keep the same? What will he observe?
8. CHALLENGE Maury called the Gulf Stream “a river in the ocean.” In three or four sentences, explain how it is like a river and how it is different.

COMMON MISTAKES

- Thinking the Gulf Stream stays in the Gulf of Mexico. It begins there, but it flows around Florida, up the American coast and all the way across the Atlantic.
- Thinking a current is the same temperature as the ocean around it. The Gulf Stream is warmer than the water beside it, which is how Franklin found it with a thermometer.
- Thinking a ship’s speed is the same whichever way it sails. A current adds to a ship’s speed when it sails with the flow and takes away from it when the ship sails against the flow.

> **Make it a game · Packet or Whaler?.** Mark a “Gulf Stream” across the middle of the floor with a long rope or a line of tape, with an arrow showing which way it flows. One player is the packet captain and one is the whaler. Each takes turns rolling a die and moving that many steps toward the far wall. A player who walks along inside the stream against its arrow must move back 2 steps each turn. A player who crosses the stream straight across in one move, or rides it in the direction of the arrow, moves ahead 1 bonus step. First to reach port wins, but only after explaining why the whalers beat the packet ships.

> **Scripture.** “They that go down to the sea in ships, that do business in great waters; These see the works of the LORD, and his wonders in the deep.” (Psalm 107:23–24, KJV)

Whalers, mail captains and sailors like the one in Homer’s painting all did business in great waters. They saw the Gulf Stream’s warm blue water, its speed and its storms. Those who watched carefully learned to use this wonder of the deep instead of fighting it.

Practice answers

1. It flows out of the Gulf of Mexico, around the tip of Florida, and then north along the coast of the United States before turning northeast across the Atlantic.
2. Timothy Folger, Franklin’s cousin, a ship captain from Nantucket. Nantucket whalers hunted whales along the edges of the Gulf Stream, so they knew where it flowed.
3. A warm current. It flows from the warm tropics near the Gulf of Mexico toward the cooler north, carrying warm water with it.
4. With the current: 12 + 4 = 16 km an hour. Against it: 12 − 4 = 8 km an hour. 48 ÷ 8 = 6 hours against the current.
5. (a) Along side A, where the water is warmest (31°C), fading by spot C. (b) 31 − 21 = 10 degrees Celsius warmer. (c) The bars for spots D and E, which are both 21°C.
6. The packet captains sailed right into the Gulf Stream and against its flow, so the current pushed them backward for days. Captains who knew about the stream crossed it quickly or stayed out of it.
7. Change: the temperature of the colored water he adds (warm). Control: the same amount of colored water at room temperature, added the same way, to compare against. Keep the same: the same bin and amount of cold water, the same amount of coloring, the same amount of added water and the same slow, gentle pour at the same spot. Observe: whether the colored water stays near the top, spreads in the middle or sinks to the bottom, and record it with drawings. He should repeat each test with fresh cold water.
8. Like a river, the Gulf Stream flows in one direction along a path that stays much the same, and it carries water and floating things with it. It even moves faster than the water around it, like a river moving past its banks. But it has no banks of land: its sides and bottom are the slower, colder ocean water around it. It is also far bigger than any river, carrying more water than all the rivers of the world together.

Unit 7 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The test is worth 50 points.

1. (5 pts) How did Matthew Fontaine Maury find the paths of the winds and currents without going to sea himself?
2. (5 pts) A logbook tally of wind directions shows: north 3, northeast 11, east 4, southeast 1, other directions 1. What is the total number of entries, which direction is most common, and what are those winds called?
3. (5 pts) What pushes most surface currents? Why do surface currents form great loops called gyres instead of flowing in straight lines?
4. (5 pts) Explain the difference between a wave and a current. Which one carried the bath toys from the North Pacific to Alaska?
5. (5 pts) A drifting buoy travels 20 km (about 12 miles) a day. How far does it travel in 15 days? How many days would it take to travel 500 km?
6. (5 pts) What is salinity? About how many grams of salt are in 3 kilograms of ocean water, if each kilogram holds about 35 grams?
7. (5 pts) An egg sinks in a glass of fresh water but floats when enough salt is stirred in. Explain why, using the word density.
8. (5 pts) Ava wants to test whether the amount of salt changes how high a plastic bead floats in water. What should she change, what should she keep the same and what should she measure?
9. (5 pts) Why were the mail packet ships from England slower than the merchant ships, and who helped Franklin find out?
10. (5 pts) A ship moves 9 km an hour in calm water. The Gulf Stream flows 3 km an hour. How fast does the ship go with the current and against it? How could a captain use a thermometer to tell when the ship has entered the Gulf Stream?

Unit project: my pathfinder’s chart of the north atlantic

Make a large hand-drawn chart of the North Atlantic Ocean in the style of Maury and Franklin. Show North America, Europe and Africa, and draw arrows for the trade winds, the westerlies, the Gulf Stream, the North Atlantic Current and the rest of the clockwise gyre. Color warm currents red and cold currents blue, mark Cape Hatteras, and add a small drawing of a packet ship and a whaler. Around the chart, attach your week of wind logbook entries and bar graph, your egg-and-salt data table and your warm-stream temperature table, and write a paragraph explaining how careful observation helped people find the “paths of the seas” (Psalm 8:8).

- **Accuracy**: Winds and currents are placed and pointed in the right directions; warm and cold currents are colored correctly; places are labeled.
- **Records**: The wind logbook, salt data table and temperature table are complete, dated and honestly recorded, with a correct bar graph.

- **Explanation**: The paragraph explains how Maury, Franklin and Folger used observations, and correctly uses the words current, gyre, salinity and density.
- **Care**: The chart is neat, colorful and easy to read, like a chart a real captain could use.

Answer key

1. He gathered thousands of old ship logbooks, copied their records of wind and current onto charts square by square and month by month, and looked for patterns. Then he gave free charts to captains who sent back new logs, so he kept getting more data.
2. 3 + 11 + 4 + 1 + 1 = 20 entries. Northeast is most common (11 entries). These are the northeast trade winds.
3. Steady winds push most surface currents. Earth's spin bends moving water (to the right north of the equator, to the left south of it), and the continents turn the currents, so they form great loops.
4. A wave carries energy while the water mostly bobs up and down in place. In a current the water itself moves along and carries things with it. A current carried the toys to Alaska.
5. 20 × 15 = 300 km (about 186 miles). 500 ÷ 20 = 25 days.
6. Salinity is how much salt is dissolved in water. 3 × 35 = 105 grams of salt.
7. Dissolved salt adds mass to the water without taking up much more space, so salt water is denser than fresh water. When the water becomes denser than the egg, it pushes up hard enough to hold the egg up, and the egg floats.
8. Change: the amount of salt (for example 0, 2, 4 and 6 spoonfuls). Keep the same: the same bead, the same amount of water at the same temperature, the same glass and level spoonfuls stirred until dissolved. Measure: whether the bead sinks or floats, or how far below the surface it floats, with a ruler. She should repeat each test.
9. The packet captains sailed against the Gulf Stream, which pushed them backward, so their voyages took about two weeks longer. Franklin's cousin Timothy Folger, a Nantucket whaling captain, explained the current and sketched its path.
10. With the current: 9 + 3 = 12 km an hour. Against it: 9 − 3 = 6 km an hour. The Gulf Stream is a warm current, so when the water temperature suddenly jumps up several degrees, the ship has entered the stream.

UNIT 8

Climate Zones

All year you have been watching the weather: water rising and falling, air pushing and rising, clouds building, storms rolling in and ocean currents carrying warmth around the globe. In this last unit you will step back and ask a bigger question: why is the weather so different from one part of the earth to another? Why do parrots live in warm forests while polar bears live on the ice? The answer is **climate**, the usual pattern of weather in a place over many years.

You will stand with Eratosthenes in ancient Egypt as he measured the earth with a shadow, and discover that the angle of the sun sets the earth's great climate zones. You will walk into the Sierra Nevada with John Muir and learn how mountains wring the rain out of the wind and leave rain shadows behind them. You will follow Henry Walter Bates into the dripping Amazon rainforest and learn why deserts lie in belts north and south of it. Finally, you will stand with Thomas Jefferson on July 4, 1776, as he wrote down the temperature, and then read a 30-year climate chart of your own town.

Along the way you will test sunlight at two angles, build a rain shadow in a baking pan, weigh "leaves" to see how a desert plant saves water, and keep a week of your own weather records to compare with your town's normals. As you learn the patterns, you will see the faithfulness of the God who promised that "cold and heat, and summer and winter" shall not cease (Genesis 8:22).

BEFORE YOU BEGIN

- Knows that warm air rises and that air pressure is lower higher up (Unit 2)
- Can explain condensation: water vapor cooling into drops (Units 1 and 3)
- Knows that oceans warm and cool slowly and that currents carry warm and cold water (Unit 7)
- Can read a bar graph and add and subtract numbers, including simple negative temperatures

MASTERY CHECKLIST

- I can explain why direct sunlight heats the ground more than slanted sunlight, and why the equator is warmer than the poles.
- I can use latitude to name the tropical, temperate and polar zones.
- I can explain how mountains make a wet windward side and a dry rain shadow on the leeward side.
- I can define a desert and a tropical rainforest and explain why each forms where it does.
- I can tell the difference between weather and climate and read a 30-year climate chart.
- I can plan a fair experiment that changes only one variable.

OPTIONAL BOOKS AND RESOURCES

- **NOAA SciJinks** (https://scijinks.gov/): Free. NOAA and NASA's weather site for students, with short articles, pictures and games about the seasons, clouds, mountains and weather. A parent can choose the pages that fit each lesson.
- **U.S. Climate Normals, from NOAA's National Centers for Environmental Information** (https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals): Free. The official 30-year normals (1991–2020) for thousands of U.S. weather stations. Use it with a parent in Lesson 8.4 to find your own town's monthly temperatures and precipitation.
- **JetStream, the National Weather Service's online weather school** (https://www.weather.gov/jetstream/): Free. Clear explanations and diagrams of global winds, air rising and sinking, and how mountains affect weather. Best read aloud by a parent for this age.

8.1 Latitude and Sun Angle ★

OBJECTIVES

- Explain why sunlight that strikes the ground straight on heats it more than sunlight that strikes at a slant, and how the sun angle changes from the equator to the poles.
- Use latitude to name the tropical, temperate and polar zones and find which zone a place is in on a globe.
- Tell how Eratosthenes used shadows and the angle of the sun to measure the earth, and test two sun angles in a fair experiment.

Warm-up. In a dim room, hold a flashlight about 30 centimeters (12 inches) above a sheet of paper and point it straight down. Trace around the spot of light with a pencil. Now tilt the flashlight so the beam hits the paper at a slant, keeping it about the same distance away, and trace that spot too. Which spot is bigger? Which one looks brighter? Where on the earth do you think the sun shines like the first spot?

Video. Coming soon. Why the equator is warmer than the poles: sun angle, latitude and climate zones (search NOAA SciJinks, NASA Space Place, Homeschool Pop (Alternate), Science Max, SciShow Kids; also short Eratosthenes measuring-the-earth animations).

KEY TERMS

climate
The usual pattern of weather in a place over many years: how warm or cold, wet or dry it tends to be in each season.

latitude
How far north or south of the equator a place is, measured in degrees. The equator is 0°, and the North and South Poles are 90°.

sun angle
How high the sun stands above the horizon. A high sun angle means the rays strike the ground nearly straight on; a low sun angle means they strike at a slant.

tropics
The warm zone around the equator, between the Tropic of Cancer (about 23.5° N) and the Tropic of Capricorn (about 23.5° S), where the noon sun can stand straight overhead.

temperate zone
The zone between the tropics and the polar circles, with warm summers, cold winters and four seasons. Most of the United States is in the northern temperate zone.

polar zone
The cold zone beyond the Arctic Circle or the Antarctic Circle (about 66.5° N and S), where the sun stays low in the sky and winters are long and dark.

CORE IDEAS

The story. In the city of Alexandria in Egypt, about 240 B.C., a Greek scholar named Eratosthenes was in charge of the greatest library in the world. He heard that far to the south, in the town of Syene (today called Aswan), something unusual happened once a year. At noon on the longest day of summer, sunlight shone straight down to the bottom of a deep well, and upright posts cast no shadow at all. The sun stood directly overhead. But in Alexandria, on that same day at noon, a tall post still cast a short shadow. Eratosthenes wondered: how could the same sun stand straight up in one town and lean in another?

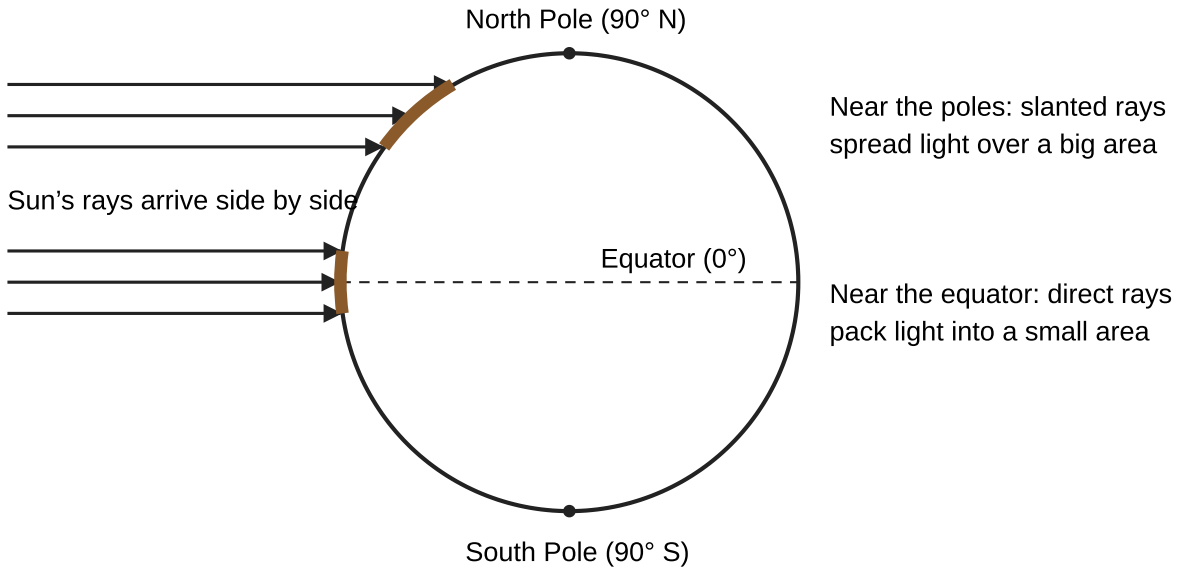
How they figured it out. Eratosthenes reasoned that the sun is so far away that its rays arrive side by side, almost parallel. If the earth were flat, those parallel rays would make the same shadows everywhere. Since they did not, the ground itself must curve. He measured the angle of the shadow at Alexandria and found it was about 7.2°, which is one-fiftieth of a full circle of 360°. So the distance from Syene to Alexandria must be one-fiftieth of the way around the whole earth! Travelers counted about 5,000 stadia (an old Greek unit of distance) between the two towns, so Eratosthenes multiplied by 50 and got 250,000 stadia for the distance around the earth. We do not know exactly how long his stadion was, but his answer was close to the true distance, about 40,000 kilometers (25,000 miles). The story comes to us from a later Greek writer named Cleomedes.

The big idea. Because the earth is a ball, sunlight strikes different places at different angles. Near the equator the noon sun is high, and its rays hit the ground nearly straight on. The light is packed into a small area, so each patch of ground gets a lot of energy and warms up. Toward the poles the same rays hit the curved earth at a slant. The light is spread out over a much larger area, so each patch gets less energy and stays cooler. You saw this with your flashlight: the slanted spot was bigger and dimmer. Scientists describe a place's position with its **latitude**, measured in degrees from 0° at the equator to 90° at each pole. The higher the latitude, the lower the sun angle and the cooler the **climate** tends to be.

Three kinds of zones. Geographers use latitude to divide the earth into climate zones. The **tropics** lie between the Tropic of Cancer (about 23.5° N) and the Tropic of Capricorn (about 23.5° S). There the noon sun can be straight overhead at least once a year, and it is warm in every month. The **polar zones** lie beyond the Arctic Circle and the Antarctic Circle (about 66.5° N and S). There the sun stays low, some winter days have no sunrise at all, and it is cold all year. Between them are the **temperate zones**, with warm summers, cold winters and four seasons. Because the earth is tilted about 23.5° as it travels around the sun, the place where the noon sun is overhead moves north and south between the two tropics through the year. That is what gives us seasons. Most of the United States is temperate, Hawaii is in the tropics, and the northern tip of Alaska is in the Arctic.

God's handiwork. One sun shining on one round, tilted earth gives the world a whole range of climates, and so a whole range of homes for living things: polar bears on Arctic sea ice, maple trees in temperate woods, and parrots in tropical forests. The psalmist watched the sun cross the sky and wrote, "There is nothing hid from the heat thereof" (Psalm 19:6).

Every place on earth receives the sun’s warmth, but not in the same amount, and that difference is where climate begins.



At the equinox, the same width of sunlight lands on a small area near the equator but is spread over a large area near the poles.

PICTURE STUDY



The Icebergs, Frederic Edwin Church, 1861 · Oil on canvas · Dallas Museum of Art, Dallas, Texas

In the summer of 1859 the American painter Frederic Edwin Church sailed north to the cold waters off Newfoundland and Labrador to sketch icebergs. He rowed close to them in a small boat and made many drawings and oil sketches, watching how the low northern sun lit the

ice. Back in his New York studio he painted this enormous picture, about 1.6 by 2.9 meters (about 5½ by 9½ feet).

When the painting was shown in London a few years later, Church added the broken mast of a wrecked ship in the front. Then the painting dropped out of sight for more than a hundred years, hanging in an English house, until it was found again in 1979. Today it hangs in the Dallas Museum of Art.

Look closely

- Find where the light is coming from. Is the sun high overhead or low in the sky?
- Look at the colors in the ice. Where do you see white, and where do you see blue and green?
- Find the broken mast. What story does it tell about this cold sea?
- Look at the sky and water. Do they look warm or cold to you? Which colors make you feel that?

Talk about it

1. Church painted far to the north of New York. Using what you learned about sun angle, why does ice last so long in these waters?
2. How would this same scene look if it were painted in the tropics?
3. Why do you think Church added the wrecked ship?

> **Safety first.** Never look at the sun, not even through sunglasses, a camera or binoculars. In the experiment you read the thermometers, not the sun. If you use a desk lamp instead of sunlight, ask an adult to set it up, keep paper and cardboard away from the bulb, and do not touch the bulb, because it gets hot.

EXPERIMENT: STRAIGHT SUN, SLANTED SUN

Question: Does sunlight that strikes at a slant warm a surface less than sunlight that strikes straight on? In Part A you will measure how big a beam of light becomes when it is tilted. In Part B you will test real sunlight with two thermometers. Before you start, write your prediction in your notebook.

What we change: the angle at which the light strikes the card. What we keep the same: the kind of card, the color of paper, the thermometers, the place and the time. What we measure: the area of the light spot (Part A) and the temperature every 5 minutes (Part B).

You will need

- Flashlight
- Graph paper with 1-centimeter squares
- Pencil and ruler
- A stack of books to hold the flashlight steady
- 2 matching outdoor thermometers (alcohol or digital, not mercury)

- 2 squares of black construction paper, about 10 centimeters (4 inches) on a side
- 2 pieces of stiff cardboard, tape and a short pencil or golf tee
- Timer and notebook

Steps

1. Part A. Rest the flashlight on a stack of books so it points straight down at the graph paper from about 30 centimeters (12 inches) away. Trace the spot of light and count the whole squares inside it.
2. Tilt the flashlight so the beam strikes the paper at a low slant. Keep the flashlight about the same distance from the paper along the beam. Trace the new spot and count its squares.
3. Divide the bigger count by the smaller count. That tells how many times more area the slanted light had to cover.
4. Part B. Tape a thermometer to each piece of cardboard and tape a black paper square over each thermometer bulb.
5. Take both cards outside on a sunny day around midday. Read both thermometers in the shade first and write the starting temperatures.
6. Set card A so it faces the sun straight on. Here is a safe trick: tape a short pencil standing straight up from the card, then turn the card until the pencil makes almost no shadow. Do not look at the sun.
7. Lean card B away from the sun so the light only skims across it at a low slant. Keep both cards in full sun, side by side.
8. Read both thermometers every 5 minutes for 20 minutes and record the numbers in a table with columns for Time, Card A (straight) and Card B (slanted).
9. Find how much each card warmed (last reading minus first reading). Was your prediction right? Write two sentences explaining what you found.

Tips

- On a cloudy day, use a desk lamp set up by an adult about 30 centimeters (12 inches) from both cards.
- Do the whole test twice. If both tests agree, you can trust your answer more.

Check your work

- I wrote a prediction before I tested.
- I changed only one thing (the angle) and kept everything else the same.
- I recorded my measurements in a table and explained what they show.

FIELD NOTEBOOK

1. Draw the earth as a circle with sun rays coming from one side, like the figure in this lesson. Color the equator area red and the polar areas blue, and label the tropics, temperate zones and polar zones.

2. Trace your two flashlight spots in your notebook and write the number of squares inside each one.
3. Draw Eratosthenes' two towns: a post with no shadow in Syene and a post with a short shadow in Alexandria. Label the 7.2° angle.

From history. Our word *climate* comes from the Greek word *klima*, which means a slope or slant. Greek geographers noticed that the farther north they traveled, the lower the sun stood and the longer the summer days grew, and they divided the known world into bands they called *klimata*. Some Greek thinkers also split the whole globe into a hot "torrid" zone around the middle, two "temperate" zones and two "frigid" zones near the poles. Those old names are still printed on some globes today.

WORKED EXAMPLES

Example 1. A flashlight pointed straight down lights up 12 squares on graph paper. The same flashlight tilted lights up 24 squares. The flashlight gives off the same amount of light both times. How much light does each square get in the tilted beam compared with the straight beam? Which beam would warm the paper more?

1. The amount of light is the same both times. Only the area changes.
2. Compare the areas: 24 squares ÷ 12 squares = 2. The tilted beam covers twice as many squares.
3. When the same light is shared by twice as many squares, each square gets half as much.
4. Less light on each square means less warming for each square.

Answer: Each square in the tilted beam gets half as much light as a square in the straight beam, so the straight beam warms the paper more. This is why places where the sun's rays strike straight on (near the equator) are warmer.

Example 2. On the first day of spring or fall (an equinox), you can find how high the noon sun stands with a simple rule: noon sun height = 90° − latitude. Find the noon sun height for Quito, Ecuador (about 0°), New Orleans, Louisiana (about 30° N) and Anchorage, Alaska (about 61° N).

1. Quito: 90° − 0° = 90°. The sun is straight overhead.
2. New Orleans: 90° − 30° = 60° above the horizon.
3. Anchorage: 90° − 61° = 29° above the horizon.
4. Compare: the farther a city is from the equator, the lower the noon sun and the more slanted its rays.

Answer: Quito about 90° (straight overhead), New Orleans about 60°, Anchorage about 29°. Anchorage's low sun spreads its light over a large area, which is one reason it is much colder.

PRACTICE

1. EASY What does latitude tell you about a place? What is the latitude of the equator, and of the North Pole?
2. EASY Name the three kinds of climate zones in order, starting at the equator and going toward a pole.
3. MEDIUM In one or two sentences, explain why slanted sunlight warms the ground less than direct sunlight.
4. MEDIUM Read the table of approximate yearly average temperatures.
   Singapore, 1° N: 27°C (81°F)
   Miami, Florida, 26° N: 25°C (77°F)
   Washington, D.C., 39° N: 15°C (59°F)
   Anchorage, Alaska, 61° N: 3°C (37°F)
   Utqiaġvik, Alaska, 71° N: −11°C (12°F)
   (a) What pattern do you see? (b) Which city is in the polar zone? (c) How many degrees Celsius warmer is Singapore than Utqiaġvik?
5. MEDIUM Use the equinox rule (noon sun height = 90° − latitude) to find the noon sun height for a town at 45° N.
6. HARD Experiment design: Sam wanted to test whether sun angle changes how warm a black card gets. He set card A facing the sun in the middle of the yard and card B tilted at a slant under a tree. Card A got hotter. Is this a fair test? What should Sam change, and what is the one variable he should test?
7. HARD Suppose Eratosthenes had measured a shadow angle of 9° instead of 7.2°, and the towns were still 5,000 stadia apart. What fraction of a full circle is 9°? How far around the earth would he have calculated?
8. CHALLENGE In the middle of summer, the sun never sets at Utqiaġvik, Alaska, for many weeks. Yet summer there is still cool. How can a place with sunlight all day and night stay cold?

COMMON MISTAKES

- Thinking summer comes when the earth is closer to the sun. The earth is actually closest to the sun in early January, during the Northern Hemisphere's winter. Seasons come from the tilt of the earth, which changes the sun angle and the length of the day.
- Thinking the equator is hot because it is closer to the sun. The difference in distance is tiny. The equator is hot because the sun's rays strike it nearly straight on.
- Thinking the sun is straight overhead at noon everywhere. In the 48 connected states the noon sun is never directly overhead, because they lie north of the Tropic of Cancer. Only places in the tropics, such as Hawaii, ever have the sun straight overhead.

Make it a game · Latitude Toss. Use an inflatable globe or a beach ball with an equator and two lines drawn on it for the Tropic of Cancer and Tropic of Capricorn, plus two smaller circles near the poles. Toss it back and forth. Wherever your right thumb lands, call out the zone (tropical, temperate or polar) and one thing about the sun there, such as "high sun, warm all year" or "low sun, long winters." Score a point for each correct answer. First to seven points wins.

Scripture. "His going forth is from the end of the heaven, and his circuit unto the ends of it: and there is nothing hid from the heat thereof." (Psalm 19:6, KJV)

The sun travels across the whole sky, and every land feels its heat. But because God made the earth round, the sun warms each land by a different amount, and that is the beginning of every climate on earth.

Practice answers

1. Latitude tells how far north or south of the equator a place is. The equator is 0°, and the North Pole is 90° N.
2. Tropical zone (the tropics), then the temperate zone, then the polar zone.
3. Slanted sunlight is spread out over a larger area, so each patch of ground gets less of the sun's energy. Direct sunlight is packed into a small area, so each patch gets more energy and warms more.
4. (a) The farther a city is from the equator (the higher its latitude), the colder its yearly average temperature. (b) Utqiaġvik, at 71° N, is north of the Arctic Circle (about 66.5° N). (c) 27 − (−11) = 38°C warmer (81 − 12 = 69°F).
5. 90° − 45° = 45° above the horizon.
6. It is not a fair test, because Sam changed two things: the angle and sun versus shade. Card B was cooler partly because it was in the shade. Sam should put both cards side by side in full sun, use the same paper, thermometers and time, and change only the angle of the card. The angle is the variable he is testing, and the temperature is what he measures.
7. 360° ÷ 9° = 40, so 9° is one-fortieth of a circle. The distance around the earth would be 40 × 5,000 = 200,000 stadia.
8. The sun stays low in the sky all day, so its rays strike at a steep slant and spread out over a large area. Each patch of ground gets only a little energy. Also, much of the energy goes into melting snow and sea ice, and white snow and ice reflect much of the sunlight away.

8.2 Mountains and Rain Shadows

OBJECTIVES

- Explain why air cools as it is pushed up a mountain and how that cooling makes clouds, rain and snow on the windward side.
- Describe a rain shadow and name a real rain-shadow place in the United States.
- Build a model mountain and measure how it changes where the “rain” falls, using a control trial.

Warm-up. Soak a kitchen sponge in water. Stand a thick book on the table as a “mountain.” Slide the sponge (a wet cloud of ocean air) up one side of the book, squeezing it a little more as it climbs, and let the drips fall on a paper towel. Then slide it down the other side onto a second paper towel. Which towel got wetter? Why was there so little water left for the far side?

Video. Coming soon. Rain shadow effect and how mountains make rain: windward and leeward sides, Olympic Mountains and Sierra Nevada (search NOAA SciJinks, National Weather Service JetStream, National Park Service, Homeschool Pop (Alternate), SciShow Kids; also nature footage of the Hoh Rain Forest and Death Valley).

KEY TERMS

elevation
How high a place is above sea level. Higher elevations are usually colder.

condensation
Water vapor (an invisible gas) cooling and turning into tiny drops of liquid water, which we see as clouds, fog or dew.

windward side
The side of a mountain that faces into the wind. Air is pushed up this side, so it is usually cloudy and wet.

leeward side
The side of a mountain facing away from the wind, where air comes down. It is usually drier.

rain shadow
A dry area on the leeward side of a mountain range, where the air has already dropped most of its water on the windward side.

CORE IDEAS

The story. In the spring of 1868 a young Scottish-born American named John Muir stepped off a ship in San Francisco and set out on foot for the mountains. He walked across California’s wide Central Valley, then up into the Sierra Nevada to Yosemite. Over the next

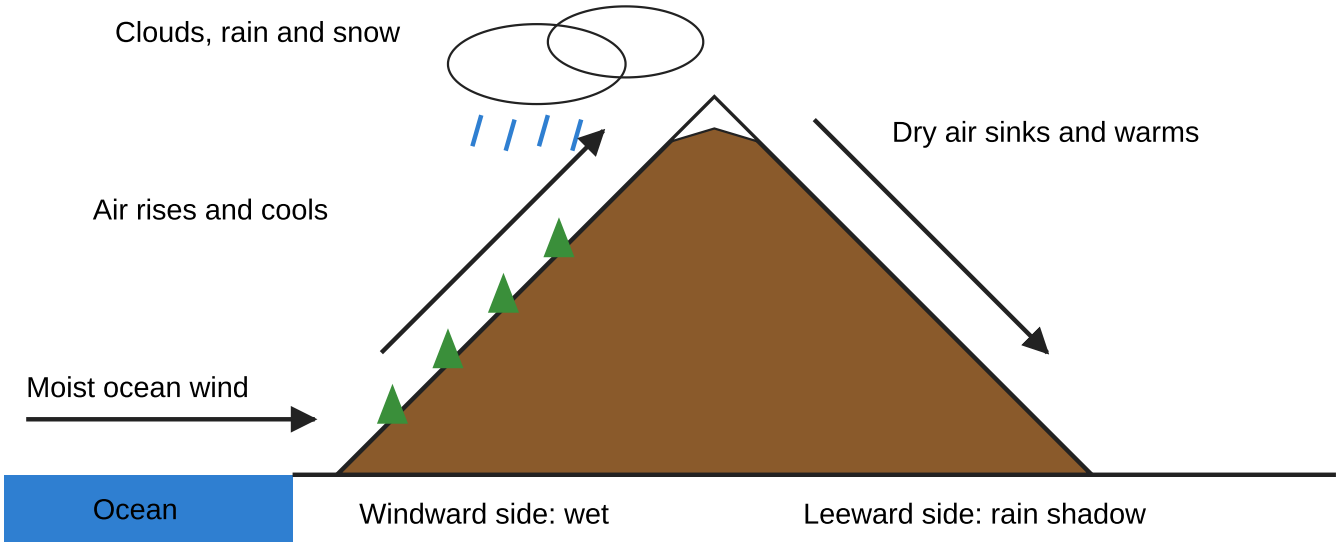
years he climbed the range again and again. He loved its bright granite, sparkling snow and clear light so much that he said it should be called not the Snowy Range but the “Range of Light.” On the western slopes Muir found deep snow in winter, rushing waterfalls and forests of giant sequoias. But when he crossed over the high passes and looked east, the land dropped steeply into a dry country of sagebrush, salty Mono Lake and bare valleys. Farther east still lies Death Valley, one of the driest places in North America, which gets only about 5 centimeters (2 inches) of rain in a whole year.

How they figured it out. How could one mountain range have a wet side and a dry side? Weather observers who carried thermometers up mountains, and later sent them aloft on balloons, found that the air gets colder as you go higher: on average about 6.5°C for every 1,000 meters (about 3.5°F for every 1,000 feet). As you learned in Unit 2, air pressure is lower high up. When air rises, it spreads out and cools. And as you learned in Unit 3, when air full of water vapor cools enough, the vapor condenses into cloud droplets. Rain gauges set out on both sides of the mountains showed the result plainly: heavy rain and snow on the slopes facing the wind, and very little on the far side.

The big idea. Wind blowing in from the ocean carries a great deal of water vapor. When it reaches a mountain range, the air has nowhere to go but up. On the **windward side**, the rising air cools, the vapor condenses, clouds pile up, and rain or snow falls. By the time the air passes over the top, it has wrung out most of its water, like a squeezed sponge. On the **leeward side**, the air sinks back down. Sinking air is squeezed by the higher pressure below and warms up, and warm, dry air makes few clouds. So the leeward side lies in a **rain shadow**: not a shadow of darkness, but a shadow of missing rain.

In the world today. You can see rain shadows all over the world. On the Olympic Peninsula in Washington State, the Hoh Rain Forest on the windward side gets about 3,550 millimeters (140 inches) of rain a year, enough for moss to hang from every branch. The town of Sequim, on the leeward side less than 80 kilometers (50 miles) away, gets only about 400 millimeters (16 inches). East of the Cascade Mountains, eastern Washington is dry wheat and sagebrush country. Mountains also change climate by their height alone. Mount Kilimanjaro in Africa stands close to the equator, yet it has snow and ice on its summit, because its **elevation** is so great. So two things shape a mountain’s climate: how high it is, and which way the wind blows against it.

God’s handiwork. Mountains work like great water towers. The snow that piles up on the windward slopes in winter melts slowly in spring and summer and runs down into streams and rivers. Farms in California’s Central Valley, below the Sierra Nevada that Muir loved, depend on that melting snow. The psalmist saw the same thing long ago: “He watereth the hills from his chambers: the earth is satisfied with the fruit of thy works” (Psalm 104:13).



Air rising up the windward side cools and drops its rain and snow. Air sinking down the leeward side warms and dries, leaving a rain shadow.

PICTURE STUDY



Among the Sierra Nevada, California, Albert Bierstadt, 1868 · Oil on canvas · Smithsonian American Art Museum, Washington, D.C.

Albert Bierstadt was born in Germany and grew up in Massachusetts. He traveled west with survey parties and made sketches of the Rocky Mountains and the Sierra Nevada. He painted this very large picture in Rome, Italy, from his sketches and memories, and showed it in Europe before it came to America. It is the same mountain range John Muir was walking into that very year.

Bierstadt did not paint one exact spot. He gathered peaks, a waterfall and a lake from different places into one grand scene. He wanted people far away to feel the size and wonder of the western mountains.

Look closely

- Find the storm clouds. Where are they, and where is the sky clearing?
- Find the waterfall. Where do you think its water came from?
- Find the animals at the edge of the lake. How small do they look next to the mountains?
- Look for snow on the peaks. Which parts of the mountain are highest and coldest?

Talk about it

1. This painting shows the windward (western) side of the Sierra Nevada. What clues in the picture show it is a wet side?
2. How would the land look if Bierstadt had painted the leeward side?
3. Why do you think Bierstadt made the light so bright on the lake?

> **Safety first.** Use only plain water in the spray bottle. Keep the pan on a tray or towel and wipe up spills right away so no one slips. If you use a small fan for wind, keep the fan's cord and plug far from the water and ask an adult to set it up.

EXPERIMENT: RAIN SHADOW IN A PAN

Question: Does a mountain change where the rain falls? You will build a model mountain in a baking pan, blow "rainy wind" at it from one side, and weigh paper towels on both sides to find out how much water landed on each.

What we change: whether the mountain is in the pan. What we keep the same: the number of sprays, the spot you spray from, the towels and the bottle. What we measure: the mass of water each towel picks up, in grams. The trial with no mountain is your control trial.

You will need

- A baking pan about 23 by 33 centimeters (9 by 13 inches)
- Modeling clay or a crumpled ball of aluminum foil, shaped into a mountain about 10 centimeters (4 inches) tall
- Paper towels, all the same kind
- A spray bottle of plain water, set to a fine mist
- A kitchen scale that measures grams
- Ruler, pencil and notebook

Steps

1. Write your prediction: which side of the mountain will get more water?
2. Fold two paper towels into squares the same size. Label one W (windward) and one L (leeward) in pencil. Weigh each one dry and record its mass in grams.

3. Set the mountain across the middle of the pan. Lay towel W on the side nearest you and towel L on the far side.
4. Hold the spray bottle at the near edge of the pan, level with the rim, and aim it across the pan toward the mountain. Give exactly 20 sprays.
5. Lift out both towels carefully and weigh them. Subtract the dry mass from the wet mass to find the grams of water each one caught.
6. Control trial: take the mountain out of the pan. Use two new dry towels in the same places, weigh them, and spray 20 times from the same spot. Weigh again and subtract.
7. Repeat both trials two more times so you have three of each. Record everything in a table with columns for Trial, Mountain or no mountain, Towel W water (g) and Towel L water (g).
8. Find the average for each towel in each kind of trial (add the three numbers and divide by 3).
9. Write two sentences: How did the mountain change where the water landed? How is your model like the real Sierra Nevada, and how is it different?

Tips

- One milliliter of water has a mass of 1 gram, so the grams your towel gains tell you how many milliliters of water it caught.
- Your model shows mountains blocking moist air. In real mountains the air also cools as it rises, which squeezes even more rain out of it.

Check your work

- I made a prediction and ran a control trial with no mountain.
- I kept the number of sprays and spraying spot the same in every trial.
- I recorded my measurements in grams and explained what they show.

FIELD NOTEBOOK

1. Draw a mountain cross-section with an arrow of wind from the ocean. Label the windward side, the leeward side, the clouds and the rain shadow, and color the wet side green and the dry side tan.
2. Draw what you would see on each side of the Olympic Mountains: mossy trees on one side and dry fields on the other. Write the yearly rainfall under each picture.
3. Record your project table and draw a small bar graph comparing the water caught by towels W and L.

> **From history.** One of the rainiest spots in the United States is Mount Waiʻaleʻale on the island of Kauaʻi in Hawaii. Steady trade winds carry moist air from the Pacific Ocean up its steep slopes day after day, and rain gauges there have recorded an average of more than 11,000 millimeters (about 450 inches) of rain a year. Only a short drive away, the leeward west side of the same island lies in a rain shadow and is sunny and dry, with beaches and the red-dirt walls of Waimea Canyon.

WORKED EXAMPLES

Example 1. A town at sea level has a temperature of 22°C (72°F) on a summer afternoon. A mountain peak nearby is 3,000 meters (about 10,000 feet) high. The air cools about 6.5°C for every 1,000 meters (about 3.5°F for every 1,000 feet). About how warm is it at the peak?

1. Find how many thousands of meters you climb: 3,000 m ÷ 1,000 m = 3.
2. Find the total cooling: 3 × 6.5°C = 19.5°C.
3. Subtract from the town's temperature: 22°C − 19.5°C = 2.5°C.
4. Check in Fahrenheit: 10,000 feet is 10 thousands, so 10 × 3.5°F = 35°F of cooling; 72°F − 35°F = 37°F.

Answer: About 2.5°C (about 37°F) at the peak, nearly cold enough for snow, even on a summer day.

Example 2. The Hoh Rain Forest gets about 3,550 millimeters (140 inches) of rain a year. Sequim, in the rain shadow, gets about 400 millimeters (16 inches). How much more rain does the Hoh get, and about how many times as much?

1. Difference: 3,550 mm − 400 mm = 3,150 mm. In inches: 140 − 16 = 124 inches.
2. Times as much: 3,550 ÷ 400 = about 8.9, which rounds to 9.
3. Picture it: for every bucket of rain that falls in Sequim, about 9 buckets fall in the Hoh Rain Forest.

Answer: The Hoh gets about 3,150 millimeters (124 inches) more rain, about 9 times as much as Sequim.

PRACTICE

1. EASY Which side of a mountain range usually gets more rain and snow, the windward side or the leeward side?
2. EASY What happens to air as it is pushed up the side of a mountain? What does that do to the water vapor in it?
3. MEDIUM A valley at 500 meters elevation is 25°C. Using a cooling of 6.5°C per 1,000 meters, about how warm is a mountaintop at 2,500 meters?
4. MEDIUM Read this table of yearly precipitation for four sample weather stations, listed from west to east across a mountain range.
   Station A, ocean coast: 1,800 mm (71 in)
   Station B, west slope: 2,500 mm (98 in)
   Station C, mountain pass: 1,600 mm (63 in)
   Station D, east valley: 300 mm (12 in)

(a) From which direction does the moist wind come? (b) Which station is in the rain shadow? (c) How much more precipitation does Station B get than Station D?

5. MEDIUM Experiment design: In “Rain Shadow in a Pan,” what is the one thing you changed? What is the control trial, and why do you need it? Name two things you kept the same.
6. HARD Seattle lies west of the Cascade Mountains, and Yakima lies east of them. Winds usually blow in from the Pacific Ocean to the west. Which city would you expect to be drier, and why?
7. HARD Mount Kilimanjaro is very near the equator, where the sun shines nearly straight down. Why does it still have snow and ice on top?
8. CHALLENGE Imagine the wind over a mountain range suddenly started blowing from the east instead of the west and kept blowing that way for years. What would happen to the rain on each side? Explain using the words windward, leeward and rain shadow.

COMMON MISTAKES

- Thinking a rain shadow is a place in the shade of a mountain. It is a dry area, not a dark one. A rain shadow can be very sunny.
- Thinking mountaintops should be warmer because they are closer to the sun. A mountain is only a tiny bit closer. The air on top is colder because air cools as it rises and spreads out.
- Thinking clouds bump into the mountain and spill their rain. Most of the rain comes from air being lifted and cooled as it climbs the slope, which makes new clouds form there.

> **Make it a game · Up and Over.** One player is a puff of ocean air and carries a cup holding ten dried beans (water vapor). Line up chairs or pillows as a mountain range. As the air climbs the windward side, the other players call out “Rising! Cooling!” and the air takes four steps up and drops two beans at each step into a “windward” bowl. At the top, count what is left and walk down the leeward side calling “Sinking! Warming!” with no beans dropped. Compare the bowls, then switch roles and let the wind blow from the other side.

> **Scripture.** “He watereth the hills from his chambers: the earth is satisfied with the fruit of thy works.” (Psalm 104:13, KJV)

God waters the high hills first. The rain and snow caught by mountains become the springs, streams and rivers that water the valleys below.

Practice answers

1. The windward side, the side that faces into the wind.
2. The air rises, spreads out and cools. When it cools enough, the water vapor condenses into cloud droplets, which can fall as rain or snow.

3. The top is 2,000 meters higher. 2 × 6.5°C = 13°C of cooling. 25°C − 13°C = 12°C (about 54°F).
4. (a) From the west (the ocean side), because the wettest stations are on the west. (b) Station D, in the east valley. (c) 2,500 − 300 = 2,200 mm more (about 86 inches more).
5. The thing changed is whether the mountain is in the pan. The control trial is the trial with no mountain; it shows how the water spreads on its own, so you can tell whether the mountain made the difference. Kept the same: the number of sprays, the spraying spot, the kind and size of towels, and the spray bottle setting (any two).
6. Yakima. Moist ocean air rises up the western (windward) side of the Cascades and drops much of its water there. When the air sinks down the eastern (leeward) side it warms and dries, so Yakima is in the rain shadow.
7. Because of its great elevation. Air gets colder as you go higher, so the very top of the mountain stays cold enough for snow and ice, even though the land around its base is warm.
8. The east side would become the windward side, so air would rise and cool there, making more clouds, rain and snow on the east. The west side would become the leeward side, where air sinks and warms, so the rain shadow would move to the west side and it would grow drier.

8.3 Deserts and Rainforests

OBJECTIVES

- Define a desert and a tropical rainforest using yearly rainfall and temperature, and classify places from climate data.
- Explain why rainforests form near the equator and why many great deserts lie near 30° north and south, and name other causes of deserts.
- Describe how desert and rainforest plants and animals are fitted for their homes, and test how a waxy covering slows water loss.

Warm-up. Wet two paper towels with the same amount of water. Lay one flat on a plate and roll the other into a tight tube. Set both on a sunny windowsill and predict which will dry first; you will check at the end of the lesson. While you wait, make two lists: three things a plant would need to live where it almost never rains, and three things a plant would need where it rains nearly every day.

Video. Coming soon. Deserts and tropical rainforests for kids: rainforest layers, desert plant and animal adaptations, why deserts form near 30° latitude (search NOAA SciJinks, National Park Service (Saguaro, Death Valley), Smithsonian, Homeschool Pop (Alternate), SciShow Kids, Moody Science classics; also nature footage of the Amazon and the Sonoran Desert).

KEY TERMS

desert
A place that gets very little precipitation, usually less than about 250 millimeters (10 inches) a year. Deserts can be hot or cold.

tropical rainforest
A thick forest near the equator that is warm all year and gets a great deal of rain, usually more than about 2,000 millimeters (80 inches) a year.

canopy
The thick upper layer of leaves and branches in a forest, like a green roof. In a rainforest, most animals live there.

humidity
How much water vapor is in the air. Rainforest air is very humid; desert air is usually very dry.

adaptation
A body part or behavior that helps a living thing survive where it lives, such as a cactus’s waxy skin or a toucan’s long bill.

CORE IDEAS

The story. In 1848 two young English naturalists, Henry Walter Bates and Alfred Russel Wallace, sailed from Liverpool and landed at Pará (today called Belém), Brazil, near the mouth of the Amazon River. Wallace went home after four years, but Bates stayed in the Amazon rainforest for eleven. He collected more than 14,000 kinds of animals, mostly insects, and thousands of them had never been described before. In his book *The Naturalist on the River Amazons* (1863), Bates described the weather of a typical day: a clear, steamy morning, clouds building up as the day grew hot, then a heavy afternoon downpour, followed by a cool, fresh evening. Day after day the same pattern returned.

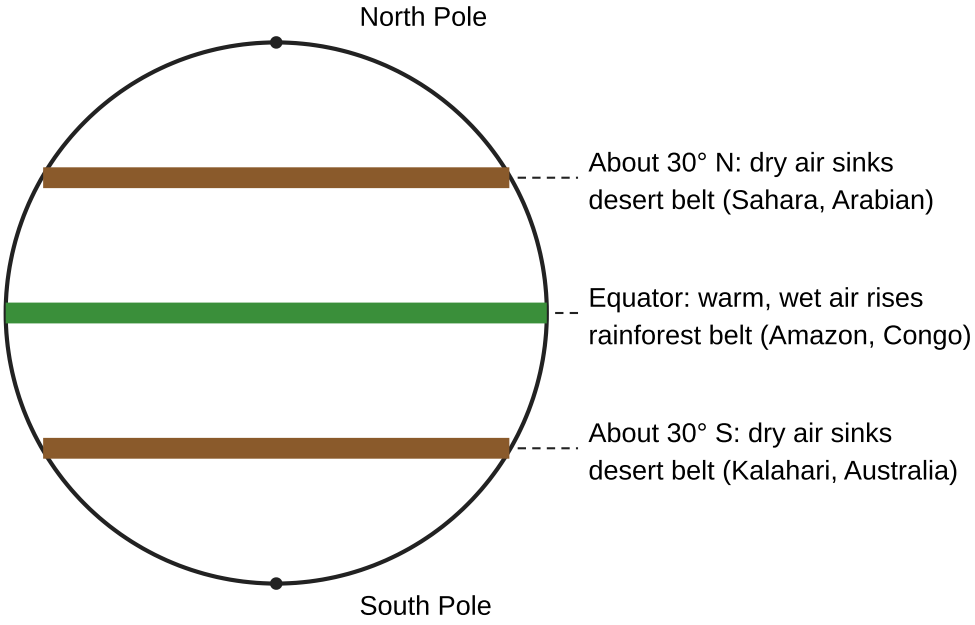
How they figured it out. Why does it rain so much near the equator? In 1735 an English lawyer and scientist named George Hadley suggested an answer while trying to explain the steady trade winds that sailors used. Near the equator the high sun heats the ground and the air strongly. Warm, moist air rises, cools and condenses into towering clouds, just as Bates saw every afternoon. High up, that air spreads out toward the poles. Later scientists found that much of it sinks back down at around 30° north and 30° south. As it sinks, it is squeezed and warms, and warm sinking air makes few clouds. Scientists today call these giant loops of rising and sinking air Hadley cells. They explain why the world has a belt of rainforests along the equator and two belts of deserts on either side: the Sahara and Arabian deserts in the north, and the Kalahari and Australian deserts in the south.

The big idea. A **desert** is any place that gets very little precipitation, usually less than about 250 millimeters (10 inches) a year. Deserts are not always hot or sandy. Antarctica is the largest desert on earth, because its cold air holds so little water vapor that very little snow falls. And only about one-fifth of the world's desert land is covered with sand dunes; most of it is gravel, rock and bare mountains. Deserts form for several reasons: sinking dry air near 30° latitude, rain shadows behind mountains (Lesson 8.2), and cold ocean currents along some coasts (Unit 7), which cool the air from below so it does not rise to make rain clouds. A **tropical rainforest** lies near the equator, stays warm in every month, often around 25 to 27°C (77 to 81°F), and usually gets more than 2,000 millimeters (80 inches) of rain a year. The largest is the Amazon rainforest in South America.

In the world today. Living things in these two climates are fitted for very different lives. A rainforest has layers: a few giant emergent trees poke above the **canopy**, the thick green roof where most of the animals live; below are the shady understory and the dim forest floor. Many rainforest leaves have pointed "drip tips" that let rain run off quickly. In the deserts of the American Southwest, the saguaro cactus has pleats that open like an accordion to store water after a rain, a waxy skin that keeps water in, and spines that shade and protect it. The little kangaroo rat can live its whole life without drinking, getting the water it needs from the seeds it eats, and many desert animals hide in burrows by day and come out in the cool night.

God's handiwork. Deserts can look empty, but they are full of life waiting for water. In some years, after a wet winter, the floor of Death Valley bursts into a carpet of yellow wildflowers called desert gold. Isaiah described just such a sight: "the desert shall rejoice, and blossom

as the rose” (Isaiah 35:1). From the dripping Amazon to the dry Sonoran Desert, the Creator fitted each living thing for its home.



Warm, wet air rises near the equator, making a belt of rainforests. Dry air sinks near 30° north and south, making belts of deserts.

PICTURE STUDY



Cattleya Orchid and Three Hummingbirds, Martin Johnson Heade, 1871 · Oil on wood · National Gallery of Art, Washington, D.C.

Martin Johnson Heade was an American painter who loved hummingbirds. In 1863 he traveled to Brazil to paint them in the wild, and he later visited Nicaragua, Colombia and

Jamaica. He was one of the first painters to show hummingbirds and orchids in their own rainforest homes instead of as specimens on a plain background.

In this small painting Heade put a bright orchid and three hummingbirds close up in front, and behind them a misty mountain forest full of moist air. Orchids like this one often grow high on the branches of rainforest trees, where they can reach the light.

Look closely

- Count the hummingbirds. How are they alike, and how are they different?
- Find the orchid. What is it growing on? Is it planted in soil?
- Look at the background. What tells you the air is warm and wet?
- Find the moss and vines. What do they tell you about how much it rains here?

Talk about it

1. Which layer of the rainforest do you think this scene shows: the canopy or the dark forest floor? Why?
2. How would a painting of a desert plant look different from this one?
3. Heade traveled far to see these birds alive. Why do you think he did not just paint them from museum specimens?

> **Safety first.** Wipe up spilled water right away. Wash your hands after handling wet paper towels and wax paper. If you visit a desert garden or cactus, look but do not touch: cactus spines can go deep into your skin.

EXPERIMENT: THE WAXY LEAF TEST

Question: Does a waxy covering or a rolled-up shape help a plant keep its water? You will make three paper-towel “leaves,” give them the same amount of water and weigh them over a day to see which one loses water fastest.

What we change: the leaf’s covering and shape. What we keep the same: the size of the towel, the amount of water, the place and the time. What we measure: the mass in grams at the start and later. The open flat leaf is the one to compare the others against.

You will need

- 3 paper towels of the same kind
- Measuring spoon (1 tablespoon, about 15 milliliters) and water
- Wax paper and 4 paper clips
- A kitchen scale that measures grams
- A plate or tray and a sunny windowsill
- Pencil, labels and notebook

Steps

1. Write your prediction: which leaf will lose the most water, and which the least?
2. Fold each paper towel into a square the same size. Wet each one with exactly 2 tablespoons (about 30 milliliters) of water.
3. Leaf A (“rainforest leaf”): leave it open and flat.
4. Leaf B (“rolled leaf”): roll it into a tight tube.
5. Leaf C (“waxy cactus skin”): fold it the same as Leaf A, then wrap it in wax paper and close the edges with paper clips. Put the same number of paper clips on Leaves A and B so every leaf has the same extra mass.
6. Weigh each leaf and record its starting mass in grams.
7. Place all three leaves side by side on the tray on a sunny windowsill.
8. Weigh each leaf again after 2 hours, 4 hours and 24 hours. Record each mass in a table with columns for Time, Leaf A, Leaf B and Leaf C.
9. For each leaf, subtract the last mass from the starting mass to find the grams of water lost. Make a bar graph of the water each leaf lost.
10. Write two or three sentences: Which leaf held its water best? How does this help explain the saguaro’s waxy skin, and why rainforest plants can have wide, open leaves?

Tips

- One milliliter of water has a mass of about 1 gram, so 30 milliliters of water is about 30 grams.
- Check your plain-towel leaves at the end of the warm-up too: did the flat towel or the rolled towel dry first?

Check your work

- I gave every leaf the same amount of water and kept them in the same place.
- I weighed carefully and recorded my numbers in a table.
- I made a bar graph and explained what my results mean for real plants.

FIELD NOTEBOOK

1. Draw a tall cross-section of a rainforest and label its four layers: emergent, canopy, understory and forest floor. Draw one animal in each layer.
2. Draw a saguaro cactus and label three adaptations: pleats, waxy skin and spines. Beside it, draw a rainforest leaf with a drip tip.
3. On a world map or tracing of a globe, color the rainforest belt along the equator green and the desert belts near 30° N and 30° S tan. Label the Amazon and the Sahara.

> **From history.** The Atacama Desert is so dry and its skies so clear that astronomers have built some of the world’s great telescopes there, high in the mountains of northern Chile. Dry air holds very little water vapor, so starlight passes through it with less blurring, and cloudy nights are rare. The same dry climate that makes the Atacama a hard place for plants makes it one of the best places on earth to study the heavens.

WORKED EXAMPLES

Example 1. Manaus, Brazil, in the Amazon, gets about 2,300 millimeters (90 inches) of rain a year and averages about 27°C (81°F). Phoenix, Arizona, gets about 180 millimeters (7 inches) a year. Classify each city, and find about how many times as much rain Manaus gets.

1. Desert rule: less than about 250 mm (10 in) a year. Phoenix gets 180 mm, which is less than 250 mm, so Phoenix is in a desert.
2. Rainforest rule: warm all year and more than about 2,000 mm (80 in). Manaus gets 2,300 mm and is warm all year, so Manaus is in a tropical rainforest.
3. Compare: 2,300 ÷ 180 = about 12.8, which rounds to 13.

Answer: Phoenix is a desert city, and Manaus is a rainforest city. Manaus gets about 13 times as much rain as Phoenix.

Example 2. A rain gauge at a sample desert station collected these amounts in one year (in millimeters): Jan 15, Feb 20, Mar 15, Apr 5, May 3, Jun 2, Jul 25, Aug 30, Sep 15, Oct 10, Nov 10, Dec 20. Find the yearly total. Is this a desert? Which months were wettest?

1. Add the first six months: 15 + 20 + 15 + 5 + 3 + 2 = 60 mm.
2. Add the last six months: 25 + 30 + 15 + 10 + 10 + 20 = 110 mm.
3. Yearly total: 60 + 110 = 170 mm. In inches: 170 ÷ 25.4 = about 6.7, or about 7 inches.
4. Compare: 170 mm is less than 250 mm, so it is a desert.
5. The biggest numbers are July (25 mm) and August (30 mm).

Answer: The station got 170 millimeters (about 7 inches), so it is a desert. July and August were wettest, from summer thunderstorms like those in the American Southwest.

PRACTICE

1. EASY About how much precipitation does a place get in a year if it is a desert?
2. EASY Antarctica is covered with ice and is very cold. Why do scientists call it a desert?
3. MEDIUM Name the four layers of a tropical rainforest from top to bottom. In which layer do most animals live?
4. MEDIUM Classify each sample place as tropical rainforest, desert, or neither, using the table.
   Place A: 2,800 mm (110 in) a year, average 26°C (79°F)
   Place B: 120 mm (5 in) a year, average 22°C (72°F)
   Place C: 150 mm (6 in) a year, average −20°C (−4°F)
   Place D: 900 mm (35 in) a year, average 12°C (54°F)

5. MEDIUM Experiment design: In the Waxy Leaf Test, what is the variable you change? Name two things you keep the same. Why must every leaf start with exactly the same amount of water?
6. HARD Explain why many of the world's great deserts lie near 30° north and 30° south of the equator.
7. HARD Henry Walter Bates noticed that in the Amazon the heavy rain usually came in the afternoon, not the morning. Why would that be?
8. CHALLENGE The Atacama Desert in Chile lies right beside the Pacific Ocean, yet some places there get less than 1 millimeter of rain a year on average. Give two reasons it can be so dry next to an ocean.

COMMON MISTAKES

- Thinking all deserts are hot and sandy. Deserts are defined by low precipitation. Antarctica is a cold desert, and most desert land is rock and gravel, not dunes.
- Thinking rainforests only get rain in a rainy season. Tropical rainforests get heavy rain in most months of the year.
- Thinking a cactus stores water in its spines. The spines are special leaves that shade and protect the plant. The water is stored in the thick, pleated stem.

Make it a game · Desert or Rainforest?. Make cards with clues such as "less than 250 millimeters of rain a year," "drip-tip leaves," "kangaroo rat," "toucan in the canopy," "waxy skin," "near 30° north," "afternoon downpours," and "Antarctica." A parent reads a card, and you jump to the right for desert or to the left for rainforest and give a reason. A correct jump with a reason scores two points. Make up three new cards of your own for the next round.

Scripture. "The wilderness and the solitary place shall be glad for them; and the desert shall rejoice, and blossom as the rose." (Isaiah 35:1, KJV)

A desert after rain can burst into flowers almost overnight. God's care reaches even the driest places on earth.

Practice answers

1. Less than about 250 millimeters (10 inches) a year.
2. Because it gets very little precipitation each year. A desert is defined by how dry it is, not by how hot it is.
3. Emergent layer, canopy, understory, forest floor. Most animals live in the canopy.
4. A: tropical rainforest (very wet and warm). B: hot desert (less than 250 mm). C: cold desert (less than 250 mm and very cold, like a polar desert). D: neither; it has moderate rain and temperatures, like a temperate place.
5. The variable is the leaf's covering and shape (open, rolled or wrapped in wax paper). Kept the same: towel size, amount of water, place, time and number of paper clips (any two). Every leaf must start with the same water so that any difference in water lost comes from the covering, not from how much water it had to begin with.

6. Warm, moist air rises near the equator, drops its rain there, and flows toward the poles high in the sky. Around 30° north and south much of this dry air sinks. Sinking air warms and makes few clouds, so these belts get little rain and become deserts.
7. The sun heats the ground and air more and more as the day goes on. By afternoon the warm, moist air is rising strongly; it cools as it rises, and the water vapor condenses into tall clouds that pour down rain. In the morning the air has not yet been heated enough to rise that much.
8. First, a cold ocean current flows north along the coast. It cools the air from below, so the air does not rise to form rain clouds (it makes fog instead). Second, the high Andes Mountains to the east block moist air from the Amazon side, so the Atacama lies in a rain shadow. It also lies near the dry sinking air of about 20° to 30° south.

8.4 My Town's Climate from a 30-Year Chart

OBJECTIVES

- Explain the difference between weather and climate, and what a 30-year climate normal is.
- Read a monthly climate chart to find the warmest and coldest months, the yearly temperature range and the yearly precipitation total.
- Find my own town's climate normals and compare them with a week of my own weather measurements.

Warm-up. Ask a parent: "What is the weather usually like on my birthday?" Then ask: "What was it like on my last birthday?" Write both answers side by side. Was last year's birthday weather the usual kind, or was it unusual? The first answer is about climate; the second is about weather.

Video. Coming soon. Weather versus climate for kids and how to read a climate graph (climograph) of monthly temperature and precipitation (search NOAA SciJinks, NOAA National Centers for Environmental Information, National Weather Service, Homeschool Pop (Alternate), SciShow Kids; avoid videos about climate policy).

KEY TERMS

weather
What the air is doing at one place and time: its temperature, wind, clouds and precipitation today or this week.

climate
The usual pattern of weather in a place, found by averaging many years of measurements.

average
A number that stands for a whole group of numbers, found by adding them all and dividing by how many there are. Also called the mean.

climate normal
A 30-year average of a weather measurement, such as the average July high temperature or the average January precipitation, for one weather station.

precipitation
Any water that falls from the sky: rain, snow, sleet or hail. Snow is melted and measured as water.

temperature range
The difference between the highest and lowest temperatures, such as the warmest month minus the coldest month.

CORE IDEAS

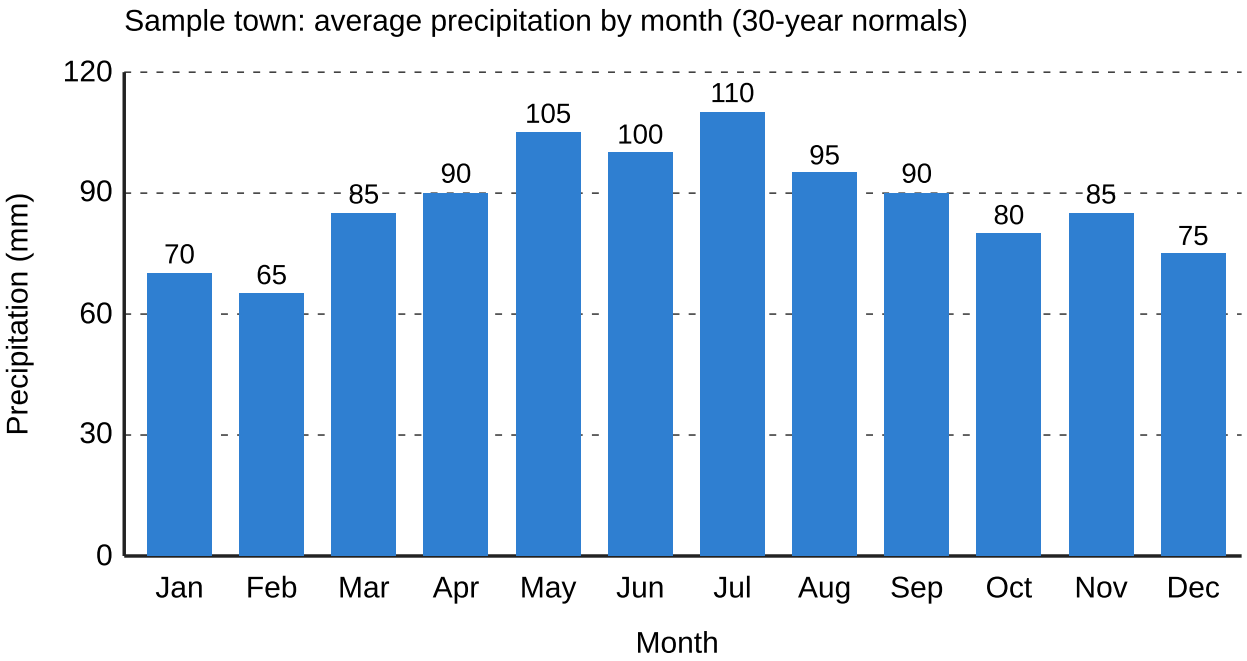
The story. On July 4, 1776, in Philadelphia, the Continental Congress approved the Declaration of Independence. That same busy day, Thomas Jefferson, who had written the first draft, bought a new thermometer from a local shop, and he wrote down the temperature in his notebook. At one o'clock in the afternoon it was 76°F (about 24°C). Jefferson went on keeping weather records for much of the rest of his life, at his home at Monticello in Virginia and wherever he traveled. He hoped that many people writing down the weather in many places, year after year, would one day show the true pattern of America's climate.

How they figured it out. One day's reading tells you the weather. To learn the climate, you need many years of readings from the same place. In 1890 the United States set up the Weather Bureau and the Cooperative Observer Program, and since then thousands of volunteers (farmers, teachers, ranchers and families) have read a thermometer and a rain gauge every day and sent in their numbers. Every ten years, scientists at NOAA take the last 30 years of these measurements for each station and average them, month by month. These averages are called **climate normals**. The newest set covers the years 1991 through 2020. Thirty years is long enough that one strangely hot summer or one very snowy winter does not throw off the average.

The big idea. Weather is what you get today; **climate** is what you can usually expect. To find an **average**, you add a set of numbers and divide by how many there are. If you averaged the temperatures of 30 Julys, you would know what a usual July is like in your town, even though no single July is exactly the same. A climate chart, sometimes called a climograph, shows a year of normals at a glance: bars for each month's average precipitation and a line or list for each month's average temperature. From it you can find the warmest and coldest months, the **temperature range**, the wettest and driest months and the yearly total of **precipitation**.

Try it and see. Your town's climate is shaped by everything you have learned in this course. Its latitude sets how high the sun climbs (Lesson 8.1). Nearby mountains may give it extra rain or put it in a rain shadow (Lesson 8.2). Its place on the globe may put it near the wet equator or a dry desert belt (Lesson 8.3). And if it is near an ocean, the water, which warms and cools slowly (Unit 7), keeps its summers cooler and its winters milder than towns far inland. You can look up your own town's normals on NOAA's Climate Normals website or on your local National Weather Service office's climate page. Choose the station closest to you, often at an airport, and compare its normals with the weather you measure yourself.

God's handiwork. Because climate follows a pattern, people can plan. Farmers use normals to know when the last spring frost usually comes, so they know when it is safe to plant. Builders use them to plan for snow on roofs, and towns use them to size their storm drains. God promised Noah after the Flood, "While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease" (Genesis 8:22). A 30-year chart is that promise written down in numbers.



Average monthly precipitation for a sample town, like the charts made from NOAA's 30-year climate normals.

PICTURE STUDY



The Harvesters, Pieter Bruegel the Elder, 1565 · Oil on wood · The Metropolitan Museum of Art, New York

Pieter Bruegel the Elder was a painter from the Low Countries (today Belgium and the Netherlands). In 1565 he painted a set of pictures showing the times of the year for a rich merchant of Antwerp. This one shows the wheat harvest in late summer, when the heat is strong and the grain is ripe.

Bruegel's farmers knew their climate without any chart. Year after year they had learned when it was warm enough to plant, when the rains came, and when the grain would be ready to cut. Their whole year of work followed the pattern of the seasons.

Look closely

- Find the people cutting wheat and the people tying it into bundles. What tools are they using?
- Find the group eating lunch under the tree. What are they eating and drinking?
- Find the man sleeping. Why might he be so tired?
- Look into the distance. What else can you see: a church, a village, ships?

Talk about it

1. What clues in the painting tell you it is a hot summer day?
2. How would knowing their climate help these farmers decide when to plant their wheat?
3. What month do you think this is? What would this same field look like in January?

> **Safety first.** Use an alcohol (red-liquid) or digital thermometer, never a mercury one. If a glass thermometer breaks, do not touch it; tell an adult. When you measure outdoors, stay away from the street, and be careful near pavement on hot days, because it can burn bare feet and hands. Ask a parent before using any website.

EXPERIMENT: MY TOWN'S CLIMATE CHART

Question: How does this week's weather compare with my town's 30-year normals? You will look up your town's climate normals with a parent, draw your own climate chart, and keep a week of your own measurements to compare.

What we measure: the temperature at the same time and place each day, and the rain in a gauge. What we keep the same: the thermometer, the spot (in the shade, about 1.5 meters or 5 feet above grass) and the time of day. What we compare: our week against the normal for this month.

You will need

- An outdoor thermometer (alcohol or digital)
- A rain gauge, or a straight-sided clear jar with a ruler taped to the side
- Graph paper, colored pencils and a ruler
- A computer with a parent, to visit NOAA's Climate Normals site or your National Weather Service office's climate page
- Notebook

Steps

1. Write a prediction: Do you think this week will be warmer, colder or about the same as normal for this month?

2. With a parent, find the weather station closest to your home and write down its 30-year normal (1991–2020) average temperature and average precipitation for each of the 12 months.
3. On graph paper, draw a bar graph of the monthly precipitation, like the figure in this lesson. Label each month along the bottom and millimeters (or inches) up the side.
4. Above or beside the bars, write each month's average temperature, or draw them as a line of dots joined together.
5. Find and write your town's warmest month, coldest month, temperature range and yearly precipitation total.
6. Hang your thermometer in the shade, about 1.5 meters (5 feet) above grass, away from walls and pavement. Set your rain gauge in an open spot.
7. For seven days, read the temperature at the same time each afternoon and check the rain gauge. Record the numbers in a table.
8. Find the average of your seven temperatures. Compare it with the normal for this month. Was your week above normal, below normal or close to normal? Was your prediction right?
9. Write two sentences explaining why one week of weather cannot change your town's climate.

Tips

- Normals for the high temperature, the low temperature and the average temperature are different numbers. Make sure you compare your afternoon readings with the average high.
- If your week was very unusual, that is weather. Climate is the pattern over 30 years.

Check your work

- I found my town's 30-year normals and drew them as a climate chart.
- I measured at the same time and place every day and recorded my numbers.
- I compared my week with the normal and explained the difference between weather and climate.

FIELD NOTEBOOK

1. Copy your town's climate chart neatly into your notebook and color the warm months red and the cold months blue.
2. Make a two-column chart titled "Weather or Climate?" and write three sentences of each kind about your own town.
3. Draw your thermometer and rain gauge where you set them up, and write one sentence about why you chose that spot.

> **From history.** Among the earliest known weather records in the American colonies were kept by a Swedish Lutheran pastor, the Reverend John Campanius, near present-day Wilmington, Delaware, in 1644 and 1645. Long before there were weather bureaus,

pastors, doctors, farmers and statesmen like Jefferson and George Washington kept weather diaries. Many of their notebooks still survive, and scientists read them today to learn what the weather was like in early America.

WORKED EXAMPLES

Example 1. Here are the 30-year average monthly temperatures for a sample town. Jan −2°C (28°F), Feb 0°C (32°F), Mar 5°C (41°F), Apr 11°C (52°F), May 17°C (63°F), Jun 22°C (72°F), Jul 24°C (75°F), Aug 23°C (73°F), Sep 19°C (66°F), Oct 12°C (54°F), Nov 6°C (43°F), Dec 0°C (32°F).
Which is the warmest month? The coldest? What is the yearly temperature range?

1. Look for the biggest number: July, 24°C (75°F).
2. Look for the smallest number: January, −2°C (28°F). Remember that a number below zero is colder than zero.
3. Range = warmest − coldest = 24°C − (−2°C). Subtracting a negative is the same as adding: 24 + 2 = 26°C.
4. In Fahrenheit: 75°F − 28°F = 47°F.

Answer: Warmest: July, 24°C (75°F). Coldest: January, −2°C (28°F). Range: 26°C (47°F), a temperate climate with cold winters and warm summers.

Example 2. The bar graph shows the sample town's average precipitation each month (in millimeters): Jan 70, Feb 65, Mar 85, Apr 90, May 105, Jun 100, Jul 110, Aug 95, Sep 90, Oct 80, Nov 85, Dec 75. Find the wettest month, the driest month and the yearly total.

(Use the map or drawing "Sample town: average precipitation by month." shown earlier in this lesson.)

1. Tallest bar: July, 110 mm. Shortest bar: February, 65 mm.
2. Add the first six months: 70 + 65 + 85 + 90 + 105 + 100 = 515 mm.
3. Add the last six months: 110 + 95 + 90 + 80 + 85 + 75 = 535 mm.
4. Yearly total: 515 + 535 = 1,050 mm. In inches: 1,050 ÷ 25.4 = about 41 inches.
5. Compare with Lesson 8.3: 1,050 mm is far more than a desert (250 mm) but less than a rainforest (2,000 mm).

Answer: Wettest: July (110 mm). Driest: February (65 mm). Yearly total: 1,050 millimeters (about 41 inches), neither a desert nor a rainforest.

PRACTICE

1. EASY Weather or climate? (a) It is raining right now. (b) Our town usually gets snow in January. (c) Summers in Phoenix are hot and dry. (d) Yesterday's high was 30°C (86°F).

2. EASY Which years does the newest set of U.S. climate normals cover? How many years is that?
3. MEDIUM The average July temperature in a town for five years was 23°C, 25°C, 24°C, 22°C and 26°C. What is the average of these five Julys?
4. MEDIUM Use the bar graph of the sample town. (a) Which months have more than 100 mm of precipitation? (b) What is the total for the spring months of March, April and May?
   (Use the map or drawing "Sample town: average precipitation by month." shown earlier in this lesson.)
5. MEDIUM Experiment design: Maria thinks a thermometer over pavement reads warmer than one over grass. Plan her test. What is the variable she changes? Name three things she must keep the same. What does she measure?
6. HARD Last January in the sample town averaged −6°C, but the 30-year normal for January is −2°C. How far from normal was it? Does one cold January mean the town's climate has changed?
7. HARD Official thermometers are kept in the shade, in a white, slatted box about 1.5 meters (5 feet) above grass. Why are all stations set up the same way?
8. CHALLENGE Two sample towns are at the same latitude. Town A: January average 10°C (50°F), July average 17°C (63°F). Town B: January average 8°C (46°F), July average 24°C (75°F). Find each town's temperature range. Which town is probably on the ocean coast? Explain.

COMMON MISTAKES

- Thinking one very hot day or one cold winter proves the climate has changed. Single days and seasons are weather; climate normals average 30 years.
- Thinking the average is the temperature you will get on a given day. Most days are a little above or below the normal; the normal is the middle of the pattern.
- Reading a thermometer set in the sun or over hot pavement. Sunshine and hot surfaces make a thermometer read too high, so it no longer tells the temperature of the air.

Make it a game · Normal or Not?. Post your town's climate chart on the wall. Each day for a week, a parent reads the day's real high temperature and rainfall from a weather report. Players guess "above normal," "below normal" or "near normal" (within 2°C or about 3°F of the average high) before checking the chart. Score a point for each correct guess. At the end of the week, add up how many days were above and below normal.

Scripture. "While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease." (Genesis 8:22, KJV)

God promised that the seasons would keep coming in their order. Because they do, a 30-year chart of the past is a trustworthy guide for planting, building and planning in the years ahead.

Practice answers

1. (a) weather, (b) climate, (c) climate, (d) weather.
2. 1991 through 2020, which is 30 years.
3. Add: 23 + 25 + 24 + 22 + 26 = 120. Divide by 5: 120 ÷ 5 = 24°C (about 75°F).
4. (a) May (105 mm) and July (110 mm). June is exactly 100 mm, which is not more than 100. (b) 85 + 90 + 105 = 280 mm (about 11 inches).
5. The variable is the surface under the thermometer (pavement or grass). She must keep the same: the kind of thermometer, the height above the ground, shade or sun (both in the shade), and the time of reading. She measures the temperature, ideally at the same times on several days.
6. −6 is 4 degrees colder than −2, so it was 4°C below normal (about 7°F below). No. One month is weather. Climate is the pattern averaged over 30 years, and every normal includes some months that are warmer and some that are colder.
7. So the readings measure the air, not sunshine striking the thermometer or heat rising off pavement or a wall, and so readings from different towns and different years can be compared fairly. If every station were set up differently, the averages would not mean the same thing.
8. Town A range: 17 − 10 = 7°C (13°F). Town B range: 24 − 8 = 16°C (29°F). Town A is probably on the coast. The ocean warms up and cools down slowly, so it keeps a coastal town cooler in summer and milder in winter, giving it a small temperature range.

Unit 8 review

Answer each question. Show your work for calculations and use complete sentences for explanations. The quiz is worth 50 points.

1. (5 pts) Explain why places near the equator are usually warmer than places near the poles. Use the words *direct* and *slanted*.
2. (5 pts) Name the climate zone (tropical, temperate or polar) for each place: (a) a town at 10° N, (b) a town at 40° N, (c) a research station at 75° S.
3. (5 pts) Eratosthenes found the shadow angle at Alexandria was 7.2°, and 360° ÷ 7.2° = 50. The towns were about 5,000 stadia apart. What distance did he calculate for the way around the earth? What did his measurement show about the shape of the earth?
4. (5 pts) Draw or describe a mountain with wind blowing from the ocean. Label or explain where the rain falls and where the rain shadow is, and why.
5. (5 pts) A town at the base of a mountain is 20°C. The peak is 2,000 meters higher. If the air cools about 6.5°C for every 1,000 meters, about how warm is the peak?
6. (5 pts) Define a desert and a tropical rainforest using rainfall amounts. Is it possible for a desert to be cold? Give an example.
7. (5 pts) Give two reasons a place can become a desert, and name one adaptation of a desert plant or animal.
8. (5 pts) Experiment design: Ben wants to test whether a waxy covering slows water loss. He puts 30 mL of water on a wax-paper-covered towel and 15 mL on an open towel, then sets one in the sun and one in the shade. List two things wrong with his test and tell how to fix them.
9. (5 pts) What is the difference between weather and climate? What is a climate normal, and how many years does it cover?
10. (5 pts) A town’s normals are: January −5°C (23°F), July 21°C (70°F). Its monthly precipitation normals add up to 820 mm. (a) What is the yearly temperature range? (b) Is the town a desert, a rainforest or neither?

Unit project: my climate zones atlas

Make a small atlas of climate, three or four pages bound with string or staples. Page 1: a world map or globe drawing with the equator, the two tropics and the two polar circles, the tropical, temperate and polar zones colored, and the rainforest belt and desert belts marked. Page 2: a labeled cross-section of a real mountain range (the Sierra Nevada, the Cascades or the Olympic Mountains) showing the windward side, the leeward side and the rain shadow, with your rain-shadow pan results. Page 3: your town’s 30-year climate chart, with your week of measurements written beside it.

On the last page, write a paragraph that explains your own town’s climate using what you learned: its latitude and sun angle, any nearby mountains or oceans, and how its yearly precipitation compares with a desert and a rainforest. Add one of your experiment tables (sun angle, rain shadow or waxy leaf) with your prediction and what you found.

- **Accuracy**: Zones, latitude lines, belts, mountain sides and climate numbers are correct and clearly labeled.
- **Records**: The climate chart and the week of measurements are complete, dated and in the correct units (with U.S. units in parentheses where used).
- **Explanation**: The paragraph explains the town's climate using sun angle, mountains or oceans, and the difference between weather and climate.
- **Experiment and care**: The experiment table shows a prediction, one changed variable and what was kept the same; the atlas is neat, colorful and easy to read.

Answer key

1. Near the equator the sun's rays strike the ground nearly straight on (direct rays), so the light is packed into a small area and warms it a lot. Near the poles the rays strike at a slant, so the same light is spread over a larger area and each patch warms less.
2. (a) Tropical (between the tropics, about 23.5° N and S). (b) Temperate. (c) Polar (beyond the Antarctic Circle, about 66.5° S).
3. 50 × 5,000 = 250,000 stadia. Because shadows were different in the two towns at the same moment, the earth's surface must be curved: the earth is round.
4. Moist ocean air is pushed up the windward side, where it cools; its water vapor condenses into clouds and falls as rain or snow. The air sinks down the leeward side, warming and drying, so the leeward side is the dry rain shadow.
5. 2 × 6.5°C = 13°C of cooling. 20°C − 13°C = 7°C (about 45°F).
6. A desert gets less than about 250 mm (10 in) of precipitation a year. A tropical rainforest is warm all year and usually gets more than about 2,000 mm (80 in) a year. Yes, deserts can be cold: Antarctica is the largest desert on earth.
7. Any two: sinking dry air near 30° north and south; a rain shadow behind mountains; a cold ocean current along the coast; cold polar air that holds little water vapor. Adaptation (any one): a cactus's waxy skin, pleated stem that stores water, or spines; a kangaroo rat that gets water from seeds; animals that come out at night.
8. He changed more than one thing. The towels started with different amounts of water, and they were in different places (sun and shade). To fix it: give both towels the same amount of water (for example 30 mL) and set them side by side in the same place, so the covering is the only thing that is different.
9. Weather is what the air is doing at one time and place, such as today's rain. Climate is the usual pattern of weather over many years. A climate normal is a 30-year average of a measurement such as the July temperature; the newest normals cover 1991 through 2020.
10. (a) 21 − (−5) = 26°C (70 − 23 = 47°F). (b) Neither: 820 mm is much more than 250 mm, so it is not a desert, and it is cold in winter with less than 2,000 mm, so it is not a tropical rainforest.

Bonus: Field Lab

This bonus unit takes everything you have learned about weather and water outdoors. Thomas Jefferson bought a thermometer on July 4, 1776, and wrote down the temperature that very afternoon. Benjamin Franklin hung bells on his lightning rod so he would know when a storm cloud passed. A team of young surveyors camped beside the Rio Grande to learn how to measure a river. In the same spirit, you will become an **observer**: someone who measures the same way, at the same times, and writes down only what is really there.

In four short field labs you will build a backyard weather station, keep a cloud photo log and test the “red sky at night” saying from Matthew 16:2–3, walk your home and street to make a storm safety map, and measure how many liters of water flow down a creek each second. Each lab is lighter than a regular lesson and happens mostly outside. By the end you will have a field notebook full of real data, gathered with your own hands, about the wind, clouds, storms and waters that God made and keeps in order.

BEFORE YOU BEGIN

- Can read a thermometer in °C and °F and a ruler in millimeters and centimeters
- Knows the main cloud types (cirrus, cumulus, stratus and nimbostratus) from Unit 3
- Knows the family storm safety plan from Unit 4
- Can add, divide by small numbers and multiply decimals such as 2 × 0.25

MASTERY CHECKLIST

- I can set up a rain gauge, a shaded thermometer and a wind vane correctly and read them at the same times each day.
- I can name a wind by the direction it comes from.
- I can estimate cloud cover in oktas and keep a fair photo log from a fixed point.
- I can use the flash-to-bang count to tell how far away lightning is, and I know where to go for lightning, tornadoes and floods.
- I can measure a creek’s width, depth and speed and calculate its discharge in liters per second.
- I can plan a fair test by changing one thing and keeping everything else the same.

OPTIONAL BOOKS AND RESOURCES

- **CoCoRaHS (Community Collaborative Rain, Hail and Snow Network)** (https://www.cocorahs.org/): Free to join. A national network of volunteers, including many families and homeschoolers, who report daily rain and snow from their own backyards. Your family can sign up, use a standard rain gauge and send in real data that weather forecasters use (Lesson 9.1).
- **NOAA SciJinks** (https://scijinks.gov/): Free. Short, clear articles and pictures from NOAA and NASA about clouds, lightning, tornadoes and weather forecasting, written

for students (Lessons 9.2 and 9.3).

- **USGS Water Science School** (https://www.usgs.gov/special-topics/water-science-school): Free. Explains how the USGS measures streamflow and how streamgages work, with diagrams and photos. A parent can also help find live flow data for a river near you (Lesson 9.4).

9.1 Backyard Weather Station

OBJECTIVES

- Build and set up a simple backyard weather station with a rain gauge, a shaded thermometer and a wind vane.
- Read and record temperature in °C and °F, rainfall in millimeters and wind direction at the same times each day.
- Add up a week of rain readings and show them on a bar graph.

Warm-up. Pour one cup (about 240 mL) of water into a tall glass with straight sides. Pour another cup into a wide, shallow bowl. Stand a ruler in each and read the depth. It is the same amount of water, but the depths are very different! Talk about it: why would a rain gauge need straight sides, and why should every rain gauge be the same shape all the way up?

Video. Coming soon. How to build a homemade weather station, rain gauge and wind vane for kids; search NOAA SciJinks, National Weather Service, CoCoRaHS, SciShow Kids, Homeschool Pop (Alternate) and Science Max.

KEY TERMS

weather station
A set of instruments kept in one place and read at the same times each day to measure the weather.

rain gauge
A straight-sided container that catches rain so you can measure how deep the rain would be on flat ground.

wind vane
A turning pointer that shows which direction the wind is coming from.

precipitation
Water that falls from clouds as rain, snow, sleet or hail.

observer
A person who carefully watches, measures and writes down what happens, the same way every time.

CORE IDEAS

The story. On July 4, 1776, in Philadelphia, the day the Declaration of Independence was approved, Thomas Jefferson did something small and ordinary. He bought a new thermometer. That same day he wrote the temperature in his notebook four times. At one o’clock in the afternoon it read 76 degrees Fahrenheit (about 24 °C). Jefferson kept weather records for much of the rest of his life, writing down temperature, wind and rain at his home

in Virginia. He knew that one reading tells you very little, but many careful readings, taken the same way day after day, show the patterns God built into the seasons.

The big idea. A **weather station** is simply good instruments, set in good places, read at the same times every day. A **rain gauge** must have straight sides and sit level in the open, away from roofs and trees, so it catches only the rain that falls from the sky. A thermometer measures the *air*, so it must hang in the shade, about 1.5 meters (5 feet) above the ground and away from hot walls and pavement. A **wind vane** turns until its arrow points *into* the wind, and winds are named for where they come *from*: a north wind blows from the north toward the south. Write every reading in one notebook with the date and time, and you are an **observer**, just like Jefferson.

In the world today. All across the United States, thousands of volunteers still read rain gauges and thermometers in their own backyards and send the numbers to the National Weather Service or to a volunteer network called CoCoRaHS. Their reports help forecasters see where storms dropped the most rain and help farmers and flood watchers. Solomon wrote that the wind “whirleth about continually” and returns “according to his circuits” (Ecclesiastes 1:6). The wind is not random noise. It follows the order God gave it, and a patient observer with a notebook can begin to see that order.

PICTURE STUDY



The Hunters in the Snow, Pieter Bruegel the Elder, 1565 · Oil on wood panel · Kunsthistorisches Museum, Vienna, Austria

Pieter Bruegel the Elder was a Flemish painter who loved to show ordinary people living through the seasons. He painted a series of pictures about the months of the year, and this is the winter one. Tired hunters trudge home through deep snow while the whole village below is frozen solid.

Bruegel had no thermometer, but he was a sharp observer. Every corner of this painting tells you how cold it is, from the ice on the ponds to the color of the sky.

Look closely

- Find three clues that tell you the temperature is below freezing (0 °C, 32 °F).
- Look at the sky. Is it clear, or covered with cloud? What color is it?
- Find the people on the ice. What are they doing?
- Look at the fire near the inn on the left. Which way is the smoke or flame leaning, and what might that tell you about the wind?

Talk about it

1. If you could set up a weather station in this village, which instrument would you read first, and what do you think it would show?
2. How do the people in the painting show that they are ready for the weather?

> **Safety first.** An adult should do all cutting of plastic bottles and any work with pins or craft knives. Use an alcohol (red-liquid) or digital thermometer, never an old mercury thermometer. Never look at the sun while you work outdoors.

EXPERIMENT: BUILD A BACKYARD WEATHER STATION

You will build three instruments, set them up in the right places and keep a weather record for one week. **Question:** How do temperature, rain and wind change over one week in my own yard? **Prediction:** Before you start, write what you think the warmest time of day will be and how many days it will rain.

What we change: nothing; we observe the days as they come. **What we keep the same:** the places of the instruments, the times we read them and the way we record. **What we measure:** temperature, rainfall in millimeters and wind direction. **Record:** a weather table in your notebook.

You will need

- A clear plastic bottle or jar with straight sides (an adult cuts off the narrow top of a bottle)
- A ruler marked in millimeters and waterproof tape
- An outdoor thermometer that shows both °C and °F
- For the wind vane: a drinking straw, a paper plate or thin cardboard, a straight pin, a pencil with an eraser and a flower pot of soil or sand
- A compass (or a phone compass used by a parent)
- Weather notebook and pencil

Steps

1. **Rain gauge.** Tape the ruler to the outside of the jar so that 0 mm is exactly at the inside bottom. Set the jar on level ground in an open spot, at least as far from any building or tree as the building or tree is tall. Push it into soil or wedge it with stones so it cannot tip.
2. **Thermometer.** Hang it on the north side of a fence post or tree trunk where it stays in the shade, about 1.5 m (5 ft) above the ground, away from pavement and walls that get hot in the sun.
3. **Wind vane.** Cut a small triangle (the arrow point) and a larger square (the tail) from the plate. Cut a slit in each end of the straw and slide them in. Find the spot where the straw balances on your finger, and an adult pushes the pin through that spot into the pencil eraser. Push the pencil into the pot and blow on the tail to check that it spins freely.
4. Use the compass to mark N, E, S and W on the rim of the pot. Set the pot in an open place with the N mark facing north.
5. Make a table with columns: Date, Time, Temperature (°C and °F), Rain since last reading (mm), Wind from, Sky.
6. Read your instruments at the same two times each day, for example 8 a.m. and 4 p.m., for seven days. Read the thermometer at eye level. Read the rain gauge at the level of the flat water surface, then empty it.
7. At the end of the week, add up the rain, find the warmest and coolest readings and draw a bar graph of rain for each day. Compare with your prediction.

Tips

- The tail of a wind vane must be bigger than the arrow point. The wind pushes the big tail away, so the point swings around to face the wind.
- If you miss a reading, leave the box empty. A real observer never guesses or makes up a number.
- In winter, bring the rain gauge in before a freeze so the ice does not crack it. To measure snow, push a ruler straight down to the ground in a flat, open place.

Check your work

- My rain gauge has straight sides, a 0 mark at the inside bottom and sits level in the open.
- My thermometer is in the shade and I can read it in both °C and °F.
- I can tell which direction the wind is coming from and name it correctly.
- I recorded seven days of readings at the same times each day.

FIELD NOTEBOOK

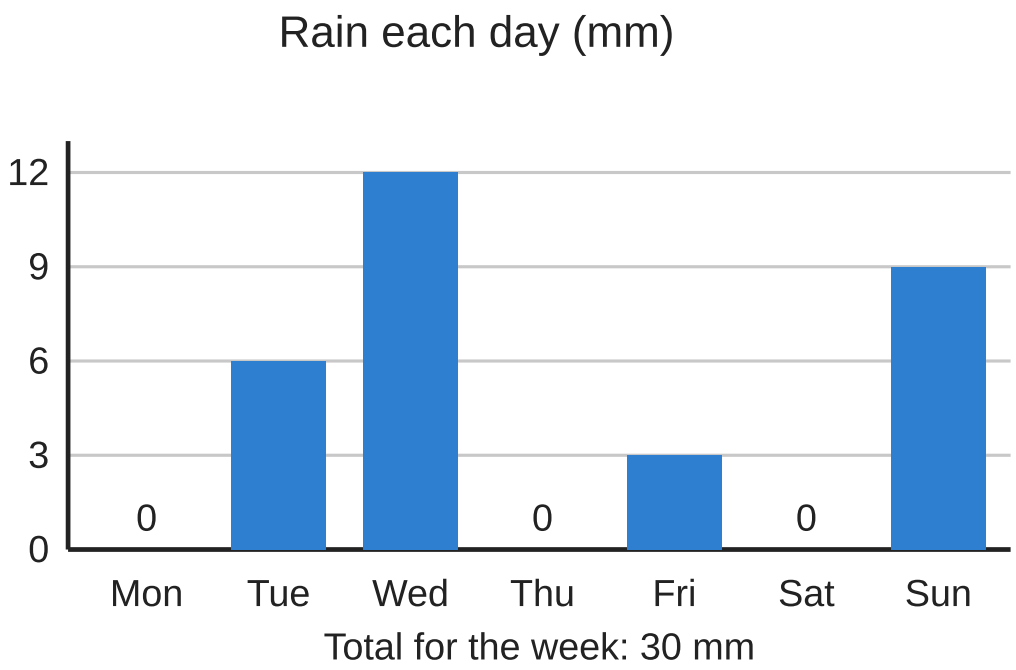
1. Draw a map of your yard from above. Mark where you put the rain gauge, the thermometer and the wind vane, and add a compass rose.
2. Draw your wind vane and label the arrow point, the tail and the pivot. Add an arrow showing the wind blowing from the west.

3. Write a weather report for one day as a radio announcer would, using your real readings: temperature, rain, wind and sky.

> **From history.** In 1890 Congress created the U.S. Weather Bureau under the Department of Agriculture, and its Cooperative Observer Program asked ordinary citizens to keep daily weather records with standard instruments. The program still runs today under the National Weather Service. Volunteers on farms, at schools and in small towns read a thermometer and a rain gauge every day, and some families have kept records at the same place for many years, passing the job from parents to children.

WORKED EXAMPLES

Example 1. Mia read her rain gauge every morning for one week. Mon 0 mm, Tue 6 mm, Wed 12 mm, Thu 0 mm, Fri 3 mm, Sat 0 mm, Sun 9 mm. How much rain fell in all? Which day was wettest? About how many inches is the total?



Mia’s rain gauge readings for one week.

1. Add the readings: 0 + 6 + 12 + 0 + 3 + 0 + 9 = 30 mm.
2. Look for the tallest bar on the graph: Wednesday, with 12 mm.
3. Count the dry days (0 mm): Monday, Thursday and Saturday, so 3 dry days.
4. One inch is about 25 mm. 30 mm ÷ 25 mm is a little more than 1, so the total is about 1.2 inches.

Answer: 30 mm of rain (about 1.2 in). Wednesday was wettest with 12 mm, and 3 days were dry.

PRACTICE

1. EASY The arrow of your wind vane points toward the west. Where is the wind coming from, and what do we call it?
2. MEDIUM Read this table from Sam’s weather station. 7 a.m.: 12 °C. Noon: 19 °C. 4 p.m.: 21 °C. When was it warmest? How many degrees Celsius did it warm up from 7 a.m. to 4 p.m.?
3. MEDIUM Ben thinks a thermometer in the sun reads higher than one in the shade. Plan a test. What will you change, what will you keep the same, and what is your control?
4. HARD Why must a rain gauge have straight sides and be set away from roofs and trees?
5. CHALLENGE Weather observers often find that about 10 cm of fresh snow melts down to about 1 cm of water. If 20 cm of snow falls, about how many millimeters of water would your rain gauge show after you melt the snow in it?

COMMON MISTAKES

- Thinking a north wind blows toward the north. Winds are named for the direction they come *from*, so a north wind blows from the north.
- Putting the thermometer in the sun. Sunshine heats the thermometer itself, so it reads warmer than the air. Air temperature is always measured in the shade.
- Using any cup or bowl as a rain gauge. The container must have straight sides and sit level, in the open, away from roofs and dripping trees.

Make it a game · Which Way, Wind?. Stand outside with your wind vane. Your parent calls out a wind name, such as “South wind!” You point to where that wind comes from and then turn to show where it is going. Then check the real wind vane: the first person to name today’s real wind correctly scores two points. Play until someone has ten points.

Scripture. “The wind goeth toward the south, and turneth about unto the north; it whirleth about continually, and the wind returneth again according to his circuits.” (Ecclesiastes 1:6, KJV)

Solomon noticed that the wind keeps turning and returning in circuits. Your wind vane will show the same thing: the wind changes from day to day, but over many days it follows patterns that God set in place.

Practice answers

1. The arrow points into the wind, so the wind is coming from the west. It is a west wind (blowing toward the east).
2. Warmest at 4 p.m. It warmed up 21 − 12 = 9 °C (about 16 °F, from about 54 °F to about 70 °F).
3. Change only the place: one thermometer in the sun, one in the shade. Keep the same: the same kind of thermometer, the same height above the ground, the same time of reading and the same waiting time (for example 10 minutes). Measure the temperature on each. The

shaded thermometer is the control, because it shows the true air temperature to compare against.

4. With straight sides, the depth of water in the jar equals the depth of rain that fell on flat ground. A jar that is wider or narrower at the bottom would make the water stand too deep or too shallow. Roofs and trees can block rain or drip extra water in, so the reading would be wrong.
5. 20 cm of snow ÷ 10 = about 2 cm of water, which is 20 mm (about 0.8 in). Real snow can be fluffier or wetter, so this is only an estimate.

9.2 Cloud Photo Log

OBJECTIVES

- Photograph the sky from the same spot, in the same direction and at the same time each day, and record the cloud type and cloud cover in oktas.
- Compare a week of cloud and sky observations with the next day's weather to test an old weather saying.
- Explain the "red sky at night" saying in Matthew 16:2–3 using the way weather usually moves from west to east.

Warm-up. Draw a rectangle on paper and divide it into 8 equal boxes, 4 across and 2 down. Look out a window at the sky and pretend the rectangle is the whole sky. Shade the number of boxes you think are covered with cloud. Have a parent do the same without peeking. Did you get the same number?

Video. Coming soon. How to estimate cloud cover and keep a cloud journal, and why "red sky at night" works; search NOAA SciJinks, NASA GLOBE Observer clouds, the UK Met Office cloud guides, SciShow Kids and Homeschool Pop (Alternate).

KEY TERMS

cloud cover
How much of the sky is hidden by clouds.

okta
One eighth of the sky. Weather observers give cloud cover from 0 oktas (clear) to 8 oktas (completely covered, or overcast).

fixed point
The exact same spot, facing the same direction, used for every photograph so that the pictures can be fairly compared.

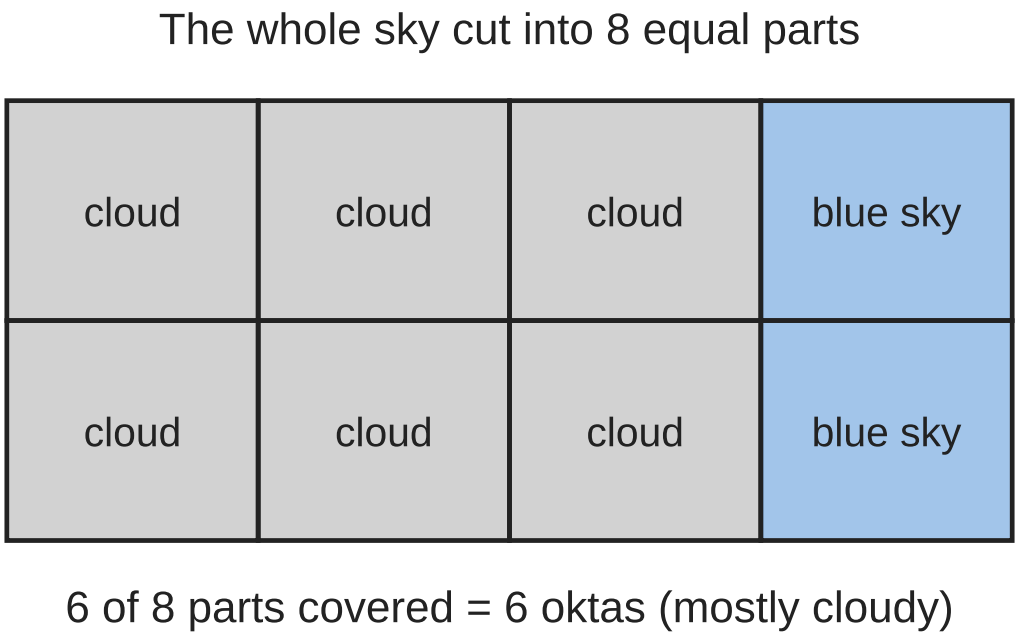
weather saying
An old rhyme or rule of thumb about forecasting, such as "red sky at night," that can be tested with careful records.

CORE IDEAS

The story. In 1857, on the beach at Sète in the south of France, the photographer Gustave Le Gray had a problem. The glass plates of his day were so sensitive to blue light that when he made the sea look right, the sky came out blank white, and when he made the clouds look right, the sea came out black. So Le Gray made two pictures, one for the sea and one for the sky, and printed them together. People were amazed to see real clouds in a photograph. Today a phone camera can catch clouds in a fraction of a second, so you can do what Le Gray worked so hard for: keep a true record of the sky.

The big idea. A cloud photo log is a weather record made of pictures. To compare one day with another, every photo must be taken from a **fixed point**: the same spot, facing the same direction, at the same time of day. Beside each photo write the date, time, cloud type and **cloud cover** in **oktas**. Picture the sky cut into 8 equal parts and count how many are covered: 0 oktas is clear, 4 is half covered and 8 is overcast. The next day, add what the weather actually did. After a week or two you can test the old sayings. High, thin cirrus clouds that thicken and lower often come a day or so before rain. Puffy cumulus clouds with flat bottoms on a summer morning usually mean fair weather.

God's handiwork. Jesus told the Pharisees that they knew how to read the sky: a red sky in the evening means fair weather, and a red, "lowring" (dark and threatening) sky in the morning means foul weather (Matthew 16:2–3). Scientists can explain why this often works. In the middle latitudes, where Israel and the United States lie, weather usually travels from west to east. The sun sets in the west, so a red evening sky means the sun is shining through clear air to the west, where tomorrow's weather is coming from. A red morning sky means the rising sun in the east is lighting up clouds that are moving in from the west. The sky is not a jumble. It follows laws God made, and people who watch it carefully can read it.



Counting cloud cover: 6 of the 8 boxes are covered, so the sky has 6 oktas of cloud.

PICTURE STUDY



The Great Wave, Sète, Gustave Le Gray, 1857 · Albumen silver print from two glass negatives (photograph) · Prints are in several museums, including the Metropolitan Museum of Art, New York

Gustave Le Gray was a French painter who became one of the first great photographers. In the 1850s he traveled to the coast to photograph the sea and sky. Because the cameras of his day could not show bright clouds and dark water in the same picture, he printed the sky from one glass negative and the sea from another.

The result looked so real that crowds lined up to see his seascapes. This photograph is a reminder that recording the sky well takes patience and cleverness.

Look closely

- Find the bright place in the clouds. Where is the sun hiding?
- Look at the clouds. Are they thin and wispy, flat and gray, or puffy? How many oktas of cloud cover would you guess?
- Find the line where the sea meets the sky. Le Gray joined his two pictures near there.
- Look at the wave on the jetty. Do you think the wind is strong or gentle?

Talk about it

1. Why would a scientist want photographs taken the same way every day instead of whenever they feel like it?
2. If you saw this sky in the evening, what weather might you expect the next day? What else would you need to know?

> **Safety first.** Never look at the sun or point a camera at it, even through clouds, and never use binoculars to look near the sun. Turn your back to the sun or face north for

> your photos. Ask permission before using a parent’s phone or camera outdoors.

EXPERIMENT: MY ONE-WEEK CLOUD PHOTO LOG

You will photograph the sky every evening for a week (two weeks is even better) and check each picture against the next day’s weather. **Question:** At my house, does a red or clear evening sky come before a fair day? **Prediction:** Write yes or no and why before you begin.

What we change: nothing; we observe. **What we keep the same:** the spot, the direction, the time of day and the camera zoom. **What we measure:** sky color, cloud type, cloud cover in oktas and the next day’s weather (use your rain gauge from Lesson 9.1). **Record:** a photo log table.

You will need

- A phone or camera (used with a parent’s permission)
- A stick, stone or chalk mark to show your fixed point
- Your 8-box sky card from the warm-up
- A cloud chart (from Unit 3 or NOAA SciJinks)
- Weather notebook, pencil and colored pencils
- Your rain gauge from Lesson 9.1

Steps

1. Choose your fixed point outdoors with a wide view of the western sky. Mark it so you stand in exactly the same place every time. Set the camera to its widest view and do not zoom.
2. Make a table with columns: Date, Time, Photo number, Sky color, Cloud type, Cloud cover (oktas), Wind from, Next day’s weather.
3. Each evening, about half an hour before sunset, stand on your mark and take one photo of the western sky, keeping the sun itself out of the picture. Do not look at the sun.
4. Hold up your 8-box card and count how many boxes are cloudy. Write the oktas, the cloud type and the sky color in your table.
5. The next morning or evening, write what the weather did that day: fair, cloudy, rain (with the millimeters from your gauge) or snow.
6. At the end of the week, count: How many red or clear evenings were followed by a fair day? How many were not? Write your results as a fraction, such as 3 out of 4.
7. Write two sentences: Did the saying work at your house this week? Why might you need more weeks to be sure?

Tips

- Print or draw small copies of your photos and glue them into your notebook beside the table.
- Clouds near the horizon look crowded together. Judge the cloud cover by looking at the whole sky, not only the edge.

- One week is a small sample. Real scientists keep records for many weeks before trusting a pattern.

Check your work

- I took every photo from my fixed point, facing the same way, at about the same time.
- I recorded cloud type and cloud cover in oktas each day.
- I wrote down what the weather did the next day.
- I can say whether the saying worked and how many times it was right.

FIELD NOTEBOOK

1. Choose your favorite photo and draw it with colored pencils. Label each kind of cloud you see.
2. Draw the 8-box sky card three times and shade it to show 1 okta, 4 oktas and 8 oktas. Write a word under each: mostly clear, half cloudy, overcast.
3. Write out Matthew 16:2–3 and draw two small skies beside it: a red evening sky and a red, lowering morning sky.

> **From history.** In 1896 weather scientists from several countries published the first *International Cloud Atlas*, with color pictures of each cloud type so that observers all over the world would use the same names. The atlas has been updated many times since, and the World Meteorological Organization now keeps it online with hundreds of photographs. When you match your photos to a cloud chart, you are doing what those first atlas makers hoped every observer would do.

WORKED EXAMPLES

Example 1. Grace kept a log for 6 evenings. Evening 1: red sky, next day fair. Evening 2: gray, next day rain. Evening 3: red sky, next day fair. Evening 4: red sky, next day rain. Evening 5: gray, next day rain. Evening 6: red sky, next day fair. How often was a red evening sky followed by a fair day?

1. Find the red evenings: 1, 3, 4 and 6. That is 4 red evenings.
2. Check the next day after each: 1 fair, 3 fair, 4 rain, 6 fair. That is 3 fair days.
3. Write it as a fraction: 3 out of 4, or 3/4.
4. Look at the gray evenings too: 2 and 5 were both followed by rain, 2 out of 2.
5. Think like a scientist: the saying worked most of the time this week, but 6 days is a small sample, so Grace should keep logging.

Answer: 3 out of 4 red evenings (3/4) were followed by a fair day. The saying mostly worked, but more weeks of records are needed to be sure.

PRACTICE

1. EASY You divide the sky into 8 parts and 2 parts have cloud. How many oktas is that? Is the sky mostly clear or mostly cloudy?
2. MEDIUM Read this photo log. Day 1: cirrus, next day rain. Day 2: cumulus, next day sunny. Day 3: cirrostratus with a halo, next day rain. Day 4: cumulus, next day sunny. Day 5: cirrus, next day cloudy but dry. Day 6: nimbostratus, next day rain. On the days with high, thin clouds (cirrus or cirrostratus), how many were followed by rain?
3. MEDIUM Leo wants to test the saying “Mares’ tails and mackerel scales make tall ships take in their sails” (wispy cirrus and rippled cirrocumulus mean wind and rain are coming). What should he record, what must he keep the same each day, and what should he compare against?
4. HARD Why should every photo in a cloud log be taken from the same spot, facing the same direction, at the same time of day?
5. CHALLENGE Explain in two or three sentences why a red sky in the morning often warns of foul weather.

COMMON MISTAKES

- Thinking clouds are smoke or steam gas. Clouds are made of billions of tiny water droplets or ice crystals floating in the air.
- Thinking a lot of cloud always means rain. Puffy fair-weather cumulus can cover much of the sky and drop no rain at all.
- Thinking one week proves a saying is true or false. A pattern must show up many times in a long record before we trust it.

> **Make it a game · Okta Guess.** Go outside together. Each player secretly writes a guess for today’s cloud cover from 0 to 8 oktas. Then hold up the 8-box card together and agree on the real count. The closest guess scores a point, and an exact guess scores two. Name the main cloud type for a bonus point. Play once a day all week and add up the scores.

> **Scripture.** “He answered and said unto them, When it is evening, ye say, It will be fair weather: for the sky is red. And in the morning, It will be foul weather to day: for the sky is red and lowring. O ye hypocrites, ye can discern the face of the sky; but can ye not discern the signs of the times?” (Matthew 16:2–3, KJV)

Jesus agreed that people could read the sky well. His deeper point was that they paid close attention to the weather but not to God’s work right in front of them. Watch the sky carefully, and watch for God’s work even more carefully.

Practice answers

1. 2 oktas. The sky is mostly clear.
2. Days 1, 3 and 5 had high, thin clouds. Days 1 and 3 were followed by rain, so 2 out of 3.

3. Record each day whether mares' tails or mackerel clouds appear, and the next day's wind and rain. Keep the same spot, direction, time of day and way of measuring rain and wind. Compare against the days when those clouds did *not* appear (the control), to see whether rain and wind really came more often after them.
4. So that the only thing changing from photo to photo is the sky. If you moved, turned or took pictures at different times, differences in trees, buildings, light and sun angle could fool you into thinking the clouds had changed.
5. In the middle latitudes, weather usually moves from west to east. In the morning the sun rises in the east and shines up onto clouds in the west. Red clouds in the morning mean clouds and moisture are moving in from the west, so rain or storms may be coming.

9.3 Storm Safety Walk

OBJECTIVES

- Walk through your home and neighborhood with a parent and mark safe and unsafe places for lightning, tornadoes and floods on a map.
- Use the flash-to-bang count to estimate how far away lightning is in kilometers and miles.
- Explain the safety rules “When thunder roars, go indoors” and “Turn around, don’t drown.”

Warm-up. Stand in the middle of your home. Point to the room on the lowest floor that has no outside windows, such as an inner hallway, closet or bathroom. Walk there (do not run) while a parent counts the seconds. That room is your first guess at a tornado shelter. How long did it take?

Video. Coming soon. Lightning, tornado and flash flood safety for kids, and how to count the distance to lightning; search National Weather Service safety pages, NOAA SciJinks, Ready.gov kids, SciShow Kids and Homeschool Pop (Alternate).

KEY TERMS

lightning rod
A metal rod on top of a building, joined by a wire to the ground, that gives lightning a safe path into the earth.

shelter
A safe place to wait out a storm. For lightning it is an enclosed building or a hard-topped car; for a tornado it is the lowest floor, in an inside room with no windows.

flash-to-bang
Counting the seconds from a lightning flash to its thunder to estimate how far away the lightning struck.

flash flood
A flood that rises very fast, within minutes or a few hours of heavy rain, often in low places, ditches and creeks.

interior room
A room in the middle of a building with no walls or windows to the outside.

CORE IDEAS

The story. In 1752 Benjamin Franklin of Philadelphia put an iron rod on the roof of his own house and ran a wire from it down into the ground. Inside, he hung two small bells on the wire, so that when a storm cloud passed overhead and the rod became electrified, the bells rang. Franklin had become sure that lightning is electricity and that a pointed metal rod

could carry it safely into the earth. In his *Poor Richard's Almanack* for the year 1753 he printed directions for making lightning rods so that ordinary families could protect their homes and barns. Franklin did not just admire storms. He studied them and then helped his neighbors get ready for them.

The big idea. Each kind of storm has its own safe place. *Lightning:* if you can hear thunder, you are close enough to be struck, so go into a closed building with wiring and plumbing, or a hard-topped car with the windows shut, and stay there until 30 minutes after the last thunder. Porches, sheds, tents and lone trees are not safe. To estimate how far away lightning is, count the seconds from flash to bang. Sound travels about 1 kilometer in 3 seconds (about 1 mile in 5 seconds). *Tornado:* go to the lowest floor, into an interior room with no windows, and cover your head. *Flood:* go to higher ground and never walk, ride or drive through moving water. The National Weather Service warns that just 15 cm (6 in) of fast-moving water can knock a grown-up down, and about 30 cm (1 ft) can carry away a car.

Try it and see. On a calm, clear day, walk your home and street with a parent like a safety inspector. Find the best tornado room. Find where you would go if thunder started while you were at the park. Look for lightning rods on church steeples and barns, low spots where water collects, storm drains and ditches to stay away from, and the high ground you would walk to in a flood. Draw it all on a map. Elihu tells Job that God "thundereth marvellously with his voice" (Job 37:5). We do not need to be afraid of storms, but we should respect them. As Proverbs 22:3 says, "A prudent man foreseeth the evil, and hideth himself."

PICTURE STUDY



A Storm in the Rocky Mountains, Mt. Rosalie, Albert Bierstadt, 1866 · Oil on canvas · Brooklyn Museum, New York

Albert Bierstadt was a German-born American painter who traveled west in the 1860s with sketchbooks and paints. In the Colorado Rockies he made studies of the peaks and the

sudden mountain storms, and back in his New York studio he painted this enormous canvas from them.

A dark storm is pouring over the mountains, but sunlight still falls on the lake and meadow. Look closely and you will find tiny people and animals far below. They are about to find out how fast a mountain storm can arrive.

Look closely

- Find the darkest storm clouds. Which part of the valley do you think the storm will reach first?
- Find the beam of sunlight. Where does it land?
- Find the tiny people, horses and tents in the valley. How big are they compared with the storm?
- Look for rain falling from the clouds. Where is it already raining?

Talk about it

1. If you were one of the people in the valley and heard thunder, where would you go? What places in the painting would be dangerous?
2. What safe places do you have near your home for a thunderstorm, a tornado and a flood?

> **Safety first.** Do the safety walk only on a calm, clear day, with a parent, never during or right after a storm. Stay well back from storm drains, culverts, ditches and creek banks, and never touch or go near fallen or low power lines. Never fly a kite near power lines or when clouds are building.

EXPERIMENT: MY STORM SAFETY MAP AND DRILL

You will walk your home and neighborhood, map the safe and unsafe places, and then time a storm drill. **Question:** Where is the safest place for each kind of storm, and how quickly can I get there? **Prediction:** Guess how many seconds it will take to reach your tornado room from your bedroom, the kitchen and the yard.

What we change: the starting place. **What we keep the same:** the safe room we go to and walking (never running). **What we measure:** the seconds it takes. **Record:** a map and a drill table.

You will need

- Large sheet of paper, pencil, ruler and colored pencils
- Clipboard
- Stopwatch or a phone timer used by a parent
- Flashlight and a bicycle helmet (for the tornado drill)
- Weather notebook

Steps

1. Inside with a parent: walk every floor. Mark the best tornado room on your map with a green star: lowest floor, interior, no windows. Mark windows and large open rooms to avoid with red X marks.
2. Find where the family keeps a flashlight, batteries, a first-aid kit and a weather radio or phone alerts. Draw them on the map.
3. Outside with a parent, on a calm, clear day: walk your yard and street. Mark with red X marks the places that are unsafe in a storm: lone tall trees, metal fences, open fields, ditches, storm drains and low spots where puddles form.
4. Mark with green stars the safe places: your house, a neighbor's house, a church or store you could reach in a few minutes. Draw an arrow toward the nearest high ground for a flood.
5. Look up! Count any lightning rods you can see on steeples, barns or tall buildings and mark them.
6. Back inside, make a drill table with columns: Starting place, My guess (seconds), Real time (seconds). Have a parent call "Tornado warning!" while you are in each starting place. Walk to the tornado room, crouch low and cover your head with your arms (or put on the helmet). Your parent records the time.
7. Compare your guesses to the real times. Write one way your family could get to safety faster.

Tips

- A tornado *watch* means conditions could make a tornado, so be ready. A tornado *warning* means one has been seen or shown on radar, so go to shelter now.
- Practice once with the lights off and a flashlight, since storms often knock out the power.
- Hang your finished map on the refrigerator so the whole family can see it.

Check your work

- My map shows a tornado room, safe lightning shelters, unsafe places and the way to high ground.
- I timed the drill from at least three starting places.
- I can say the rules for lightning, tornadoes and floods without looking.

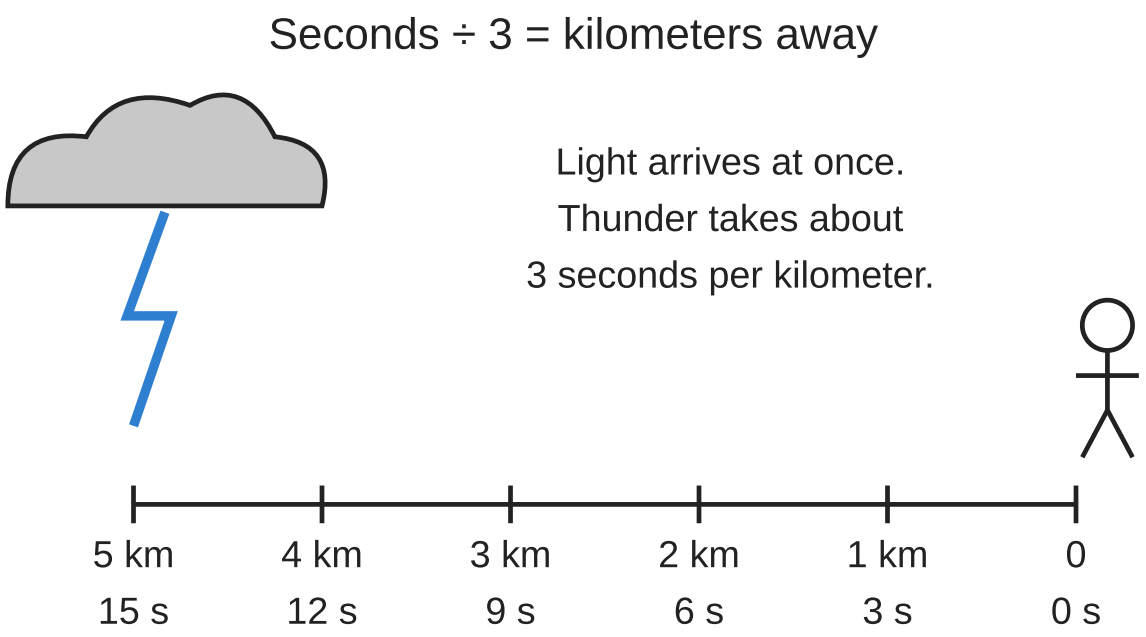
FIELD NOTEBOOK

1. Draw a house with a lightning rod. Show the rod, the wire down the side of the house and the ground rod, and draw an arrow showing the lightning's path into the earth.
2. Make a three-column chart: Thunderstorm, Tornado, Flood. Under each, write where to go and one thing never to do.
3. Draw a small copy of Bierstadt's valley with the storm coming. Add a green star where the travelers could find the safest shelter and a red X on the most dangerous spots.

From history. Not every early lightning scientist was as careful as Franklin hoped people would be. In 1753 Georg Wilhelm Richmann, a scientist in St. Petersburg, Russia, was killed by lightning while measuring electricity from a storm with a rod attached to his equipment indoors. His death showed the world how powerful lightning is, and it is one reason safety rules for lightning are taken so seriously today. Never try lightning experiments or fly a kite near a storm.

WORKED EXAMPLES

Example 1. You see a flash of lightning and count 15 seconds before you hear the thunder. About how far away was the lightning, in kilometers and in miles? What should you do?



Flash-to-bang: every 3 seconds between the flash and the thunder is about 1 kilometer.

1. Sound travels about 1 km in 3 seconds. 15 ÷ 3 = 5, so the lightning was about 5 km away.
2. Sound travels about 1 mile in 5 seconds. 15 ÷ 5 = 3, so that is about 3 miles.
3. You heard the thunder, so you are close enough to be struck. Lightning can strike many kilometers away from the storm.
4. Go inside a building or a hard-topped car right away and wait 30 minutes after the last thunder.

Answer: About 5 km (about 3 miles) away. Go indoors now, because if you can hear thunder, you are close enough to be struck.

PRACTICE

1. EASY A tornado warning has been given for your town. Where in your house should you go?
2. MEDIUM You count 9 seconds from flash to bang. About how many kilometers away is the lightning? About how many miles?
3. MEDIUM Read this table of flash-to-bang counts taken a few minutes apart. 4:00 p.m.: 30 seconds. 4:05 p.m.: 21 seconds. 4:10 p.m.: 12 seconds. How far away was the lightning each time? Is the storm coming closer or moving away? What should you have done at 4:00?
4. HARD Kate wants to find which low spot in her yard fills with the most water after a rain. Plan the test. What will she measure, what will she keep the same, and why should she wait until the rain has stopped?
5. CHALLENGE Explain why standing under a lone tree in a field during a thunderstorm is dangerous.

COMMON MISTAKES

- Thinking lightning never strikes the same place twice. Tall buildings, towers and trees can be struck many times, even in a single storm.
- Thinking a car’s rubber tires keep you safe from lightning. It is the hard metal roof and body that carry the electricity around you to the ground, so a convertible or open vehicle is not safe.
- Thinking shallow water on a road is safe to cross. Moving water is stronger than it looks and can hide a washed-out road. Turn around, don’t drown.

> **Make it a game · Storm Drill Dash.** Your parent calls out one storm word at a time: “Thunder!” “Tornado warning!” or “Flooded road!” Walk quickly (no running) to the right safe place or do the right action, and say the rule out loud: “When thunder roars, go indoors,” “Lowest floor, inside room,” or “Turn around, don’t drown.” Each correct place and rule scores a point. Then switch, and you call the storms for your parent.

> **Scripture.** “God thundereth marvellously with his voice; great things doeth he, which we cannot comprehend.” (Job 37:5, KJV)

Job 37 describes thunder, lightning, snow and whirlwinds as the works of God. A storm reminds us how great and powerful He is. We honor Him by marveling at storms from a safe place and by caring for our families with a plan.

Practice answers

1. To the lowest floor (a basement or storm cellar if you have one), into an interior room with no windows, such as a closet, hallway or bathroom. Crouch low and cover your head.
2. 9 ÷ 3 = 3 km. 9 ÷ 5 is about 2 miles (1.8 miles).

3. 30 ÷ 3 = 10 km, 21 ÷ 3 = 7 km, 12 ÷ 3 = 4 km. The storm is coming closer. You could already hear thunder at 4:00, so you should have gone indoors right then.
4. She measures the water depth in each low spot with a ruler (in mm or cm). She keeps the same ruler, measures every spot after the same rain and at the same time after it stops, and measures at the deepest point of each puddle. She waits until the rain has stopped and there is no thunder for 30 minutes so she is safe, and so that every spot is measured under the same conditions.
5. Lightning often strikes the tallest object around, and a lone tree in a field is the tallest thing there. When lightning hits the tree, the electricity can jump to a person nearby or spread through the ground around the tree. It is much safer to get inside a building or a hard-topped car.

9.4 Measuring a Creek

OBJECTIVES

- Measure a creek's width, average depth and surface speed safely from the bank or the shallow edge.
- Calculate how much water flows past one spot each second (the discharge) in cubic meters and liters per second.
- Explain how a small creek is part of the path that carries water to the sea (Ecclesiastes 1:7) and how USGS streamgages watch rivers today.

Warm-up. Turn on the kitchen faucet just a little and time how many seconds it takes to fill a 1-liter bottle (about 1 quart). Then open the faucet wider and time it again. Divide 1 liter by the seconds to find the flow in liters per second. A creek has a flow too, and today you will measure it.

Video. Coming soon. How hydrologists measure stream flow with a float or current meter, and how a USGS streamgage works; search USGS Water Science School, USGS streamgaging videos, NOAA SciJinks, Science Max and nature footage of creeks.

KEY TERMS

creek
A small natural stream of flowing water, smaller than a river.

cross-section
The shape you would see if you sliced straight across a creek from bank to bank: its width and its depth.

velocity
How fast the water moves, measured in meters per second (or feet per second).

discharge
The amount of water flowing past one spot each second. Width × average depth × velocity.

streamgage
A station beside a creek or river that measures the water level and flow, often sending the numbers online every few minutes.

CORE IDEAS

The story. In the winter of 1888 to 1889, a group of young men camped beside the Rio Grande at Embudo, New Mexico. They had been sent by the U.S. Geological Survey, led by the explorer John Wesley Powell, to learn a new skill: measuring how much water a river carries. Farmers in the dry West needed to know how much water there was to share. At Embudo the men stretched lines across the river, measured its depth again and again and

timed how fast the water moved. The streamgage they set up there became the first one run by the USGS, and the Rio Grande is still measured at Embudo today.

The big idea. To find how much water a creek carries, you need three measurements. First, the **width** from one edge of the water to the other. Second, the **average depth**: measure the depth at several places across the creek, add them and divide by how many you measured. Width times average depth gives the area of the creek's **cross-section**. Third, the **velocity**: drop a float such as an orange upstream and time how long it takes to drift a measured distance. Multiply all three, with every length in meters, and you get the **discharge** in cubic meters per second. One cubic meter holds 1,000 liters, so it is easy to change the answer into liters.

God's handiwork. Every creek is a small part of a great circuit. Solomon wrote, "All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again" (Ecclesiastes 1:7). The water in your creek will join a larger stream, then a river, then the sea. The sun will lift some of it back into the sky, and it will fall again as rain on the hills. Today the USGS runs thousands of streamgages, and anyone can look up the flow of a nearby river online. When heavy rain falls, those numbers warn towns that a flood is coming.

PICTURE STUDY



Kindred Spirits, Asher Brown Durand, 1849 · Oil on canvas · Crystal Bridges Museum of American Art, Bentonville, Arkansas

Asher B. Durand painted this picture in memory of his friend, the painter Thomas Cole, who had died the year before. It shows Cole and the poet William Cullen Bryant standing on a ledge in the Catskill Mountains of New York, looking down at a stream rushing through a deep gorge called a clove.

Durand loved to paint the woods and waters of America exactly as they looked. He told young painters to study nature closely, the same way a scientist does.

Look closely

- Find the stream at the bottom of the gorge. Follow it with your finger. Where is it coming from, and where is it going?
- Find the waterfall. What makes the water fall at that spot?
- Look at the rocks in and beside the stream. Are they sharp or rounded? What might have rounded them?
- Look at the two men. What are they looking at?

Talk about it

1. If you stood beside this stream with a tape measure and an orange, how would you find out how much water it carries?
2. Where will the water in this stream go after it leaves the mountains?

> **Safety first.** Only visit a creek with an adult. Choose a calm, shallow spot with gentle banks, and do as much as you can from the bank. Never wade above your knees, never go in fast-moving water, and never go near a creek during or after heavy rain or when the water is high or muddy. Wear shoes with good grip, since wet rocks are slippery. Do not drink creek water, and wash your hands afterward. Get permission before going onto private land.

EXPERIMENT: HOW MUCH WATER PASSES BY?

You will measure a small creek the way the USGS men did at Embudo, only on a smaller scale. **Question:** How many liters of water flow past one spot in my creek each second? **Prediction:** Write a guess. Is it more like a bathtub per second, a bucket per second or a cup per second?

What we change: nothing on the first visit; on a second visit, the day (for example, a few days after a rain). **What we keep the same:** the measuring spot, the float, the distance and the method. **What we measure:** width, depth at three places, float time. **Record:** a creek data table and a cross-section drawing.

You will need

- A measuring tape at least 5 m (about 16 ft) long
- A meter stick or yardstick
- An orange or a small rubber ball (an orange floats low, so the wind does not push it much)
- A stopwatch or a phone timer used by a parent
- Two sticks or small flags to mark the start and finish
- A net or a helper downstream to catch the float

- Waterproof shoes or rubber boots, notebook and pencil

Steps

1. With your adult, choose a straight, shallow stretch of creek where the water moves smoothly and you can reach both banks safely.
2. Measure the width of the water from edge to edge. If you can, stretch the tape across from bank to bank with a helper on each side.
3. Measure the depth at three places across the creek: one quarter of the way across, the middle and three quarters of the way across. Stand the meter stick straight up on the bottom and read where the water surface touches it. Add the three depths and divide by 3.
4. Measure 5 m (about 16 ft) along the bank and mark the start and finish with sticks.
5. Drop the orange in the middle of the creek a little upstream of the start. Start the timer when it passes the start stick and stop it at the finish stick. Do this three times and find the average time.
6. Find the velocity: distance ÷ average time, in meters per second.
7. Change the depth from centimeters to meters (divide by 100). Then find the discharge: width × average depth × velocity = cubic meters per second. Multiply by 1,000 to get liters per second.
8. Draw the cross-section in your notebook, like the figure in the worked example, with your real numbers. If you can, come back after a dry week or a rainy one and measure again.

Tips

- Water at the surface moves faster than water near the bottom, where the creek bed slows it down. Real hydrologists often multiply a float answer by about 0.8 to correct for this. Your answer is a good estimate, a little on the high side.
- If the orange gets stuck on a rock or swirls in an eddy, do not count that run. Try again.
- Look up a USGS streamgage near you on the USGS water data website and compare its flow to yours. Rivers can carry thousands of times more water than a small creek.

Check your work

- I measured width, three depths and three float times.
- I changed centimeters to meters before multiplying.
- I found the discharge in cubic meters per second and in liters per second.
- I stayed safe: an adult was with me and I did not wade above my knees.

FIELD NOTEBOOK

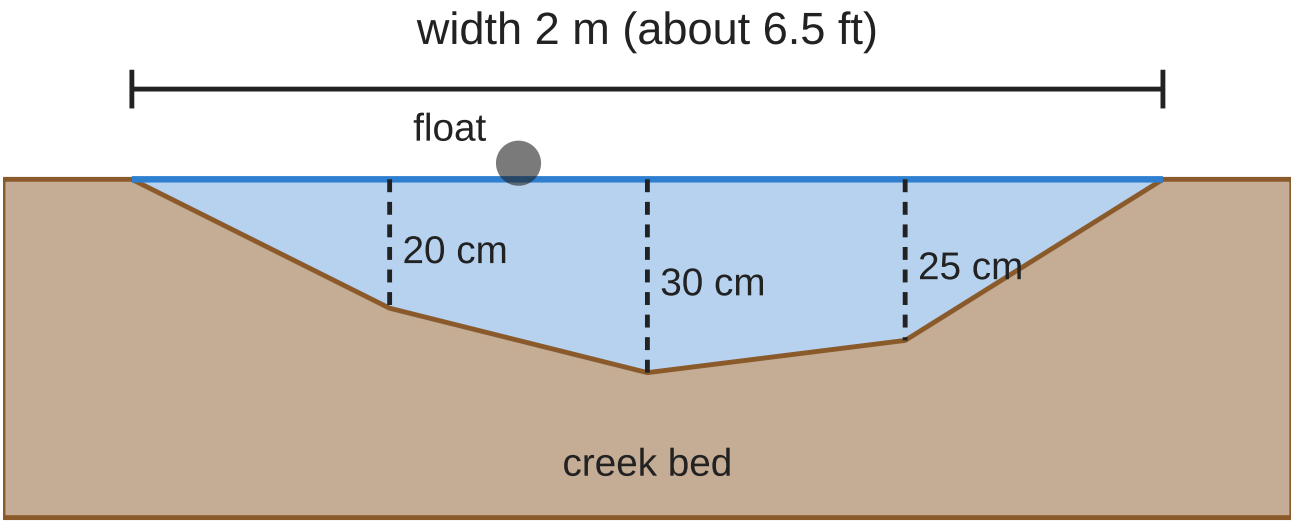
1. Draw your creek from above. Show the bank, the start and finish sticks, where you measured the depths and an arrow for the direction of flow.
2. Draw a creek animal or plant you found (a water strider, crayfish, minnow, moss or cattail) and write where you saw it.

3. Draw a map arrow by arrow: my creek → a larger stream or river → the sea. Look at a map with a parent to name each one.

From history. People have measured rivers for a very long time. On Roda Island in the Nile River at Cairo, Egypt, stands a stone well with a tall marked column inside called a Nilometer. It was built in the year 861 to measure how high the Nile rose each flood season, which told farmers whether the harvest would be good or poor. The Nilometer still stands today, more than a thousand years later.

WORKED EXAMPLES

Example 1. A creek is 2 m wide (about 6.5 ft). Its depth is 20 cm, 30 cm and 25 cm at three places across. An orange floats 10 m (about 33 ft) in 20 seconds. Find the average depth, the velocity and the discharge in liters per second.



average depth = (20 + 30 + 25) ÷ 3 = 25 cm

A creek cross-section: measure the width, then the depth at three places, and average the depths.

1. Average depth: (20 + 30 + 25) ÷ 3 = 75 ÷ 3 = 25 cm. Change to meters: 25 cm = 0.25 m.
2. Velocity: 10 m ÷ 20 s = 0.5 m per second.
3. Cross-section area: width × average depth = 2 m × 0.25 m = 0.5 square meters.
4. Discharge: area × velocity = 0.5 × 0.5 = 0.25 cubic meters per second.
5. Change to liters: 0.25 × 1,000 = 250 liters per second (about 66 gallons per second).

Answer: Average depth 25 cm (0.25 m), velocity 0.5 m/s, discharge 0.25 cubic meters per second, which is 250 liters per second (about 66 gallons per second).

PRACTICE

1. EASY What three measurements do you need to find a creek's discharge?
2. MEDIUM Read this table of float runs over 5 m (about 16 ft). Run 1: 10 s. Run 2: 12 s. Run 3: 8 s. What is the average time? What is the velocity?
3. MEDIUM Noah wonders whether the water flows faster in the middle of the creek or near the bank. Plan a fair test. What will he change, what will he keep the same, and what will he measure?
4. HARD A creek is 3 m wide, has an average depth of 20 cm and a velocity of 0.5 m per second. Find the discharge in cubic meters per second and in liters per second.
5. CHALLENGE After a heavy rain, the same creek is just as wide, but it is twice as deep and flows twice as fast. How many times more water is it carrying? Why is this a time to stay away?

COMMON MISTAKES

- Thinking water moves fastest along the bottom or at the edges. The bed and banks slow the water by rubbing against it, so the fastest water is usually near the surface in the middle.
- Thinking the deepest creek always carries the most water. A wide, fast, shallow creek can carry more than a deep, slow one, because width, depth and speed all count.
- Multiplying centimeters by meters. Change every length to meters first, or the answer will be 100 times too big.

> **Make it a game · Poohsticks Speed Race.** This game comes from A. A. Milne's *The House at Pooh Corner*. On a low footbridge with railings, with an adult, each player picks a stick and drops it at the same moment from the upstream side. Hurry (walking!) to the downstream side and watch for the first stick to come out. The winner scores a point. For a science bonus, measure the width of the bridge and time the sticks to find the water's speed in meters per second.

> **Scripture.** "All the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again." (Ecclesiastes 1:7, KJV)

Your creek is part of the water cycle God designed. Its water runs toward the sea, rises again as vapor, falls as rain and returns to the hills. Measuring a creek lets you see one small piece of that great, faithful circuit.

Practice answers

1. The width, the average depth and the velocity (speed) of the water.
2. Average time: (10 + 12 + 8) ÷ 3 = 30 ÷ 3 = 10 s. Velocity: 5 m ÷ 10 s = 0.5 m per second.
3. Change only where he drops the float: the middle or near the bank. Keep the same float, the same 5 m distance, the same stretch of creek and the same day. Measure the time for each run, and do at least three runs in each place, then compare the average times. (He will most likely find the middle is faster, because the bank and bottom slow the water near them.)

4. 20 cm = 0.2 m. 3 × 0.2 × 0.5 = 0.3 cubic meters per second = 300 liters per second (about 79 gallons per second).
5. Discharge = width × depth × velocity, so doubling the depth and doubling the velocity makes 2 × 2 = 4 times as much water. Deeper, faster water can knock a person down and sweep them away, and the banks may be slippery or crumbling, so stay well back until the creek goes down.

Unit 9 review

This is a short field lab review. Answer each question. Show your work for calculations and use complete sentences for explanations. The review is worth 50 points.

1. (8 pts) Your rain gauge showed 4 mm, 0 mm, 11 mm and 5 mm on four mornings. How much rain fell in all? Name two rules for where to set up a rain gauge.
2. (8 pts) Your wind vane’s arrow points east. What is the wind called? Why must a thermometer for measuring air temperature hang in the shade?
3. (8 pts) In your cloud photo, 3 of the 8 parts of the sky have cloud. How many oktas is that? Give one reason to take every photo from the same fixed point at the same time.
4. (8 pts) Jesus said, “When it is evening, ye say, It will be fair weather: for the sky is red” (Matthew 16:2). Explain why a red evening sky often comes before fair weather.
5. (10 pts) You count 12 seconds from a lightning flash to its thunder. About how far away was it in kilometers? What should you do? Where should you go in a tornado warning, and what is the rule for a flooded road?
6. (8 pts) A creek is 4 m wide, has an average depth of 25 cm, and a float travels 10 m in 20 seconds. Find the velocity and the discharge in liters per second.

Unit project: my field lab notebook

Gather your four field labs into one field notebook. Include at least one week of weather station readings with a bar graph of rainfall, your cloud photo log with oktas and your test of the “red sky” saying, your storm safety map with drill times, and your creek data table with a labeled cross-section drawing and your discharge calculation. Finish with a one-page “Field Report” that tells the most surprising thing you measured, one pattern you noticed and one question you would like to test next.

- **Accurate data**: Readings are dated and timed, taken the same way each time, written in correct units (°C and °F, mm, oktas, meters, seconds), and no numbers are guessed or made up.
- **Correct calculations**: Rain totals, flash-to-bang distances, averages and the creek discharge are worked out step by step and are correct.
- **Fair tests and safety**: Each lab names what was changed, what was kept the same and what was measured, and the safety map and creek lab show careful safe choices.
- **Care and explanation**: Drawings are neat and labeled, and the Field Report clearly explains a pattern found in the data and what it shows about the order God built into weather and water.

Answer key

1. 4 + 0 + 11 + 5 = 20 mm (about 0.8 in). Rules: set it level, in the open, away from roofs and trees (as far from them as they are tall), so it catches only rain falling from the sky. It must have straight sides.

2. An east wind, because the arrow points into the wind and winds are named for where they come from. The thermometer must be in the shade because sunshine heats the thermometer itself and makes it read warmer than the air.
3. 3 oktas (partly cloudy). Taking every photo from the same spot, direction and time means the only thing that changes is the sky, so the photos can be fairly compared.
4. In the middle latitudes, weather usually moves from west to east. The sun sets in the west, so a red evening sky means sunlight is shining through clear air to the west, where tomorrow’s weather is coming from.
5. 12 ÷ 3 = 4 km (about 2.4 miles). Go indoors to a closed building or hard-topped car right away, because if you can hear thunder you are close enough to be struck, and wait 30 minutes after the last thunder. Tornado: the lowest floor, an interior room with no windows, covering your head. Flooded road: turn around, don’t drown; never walk or drive through moving water.
6. Velocity: 10 m ÷ 20 s = 0.5 m/s. Depth: 25 cm = 0.25 m. Discharge: 4 × 0.25 × 0.5 = 0.5 cubic meters per second = 500 liters per second (about 132 gallons per second).