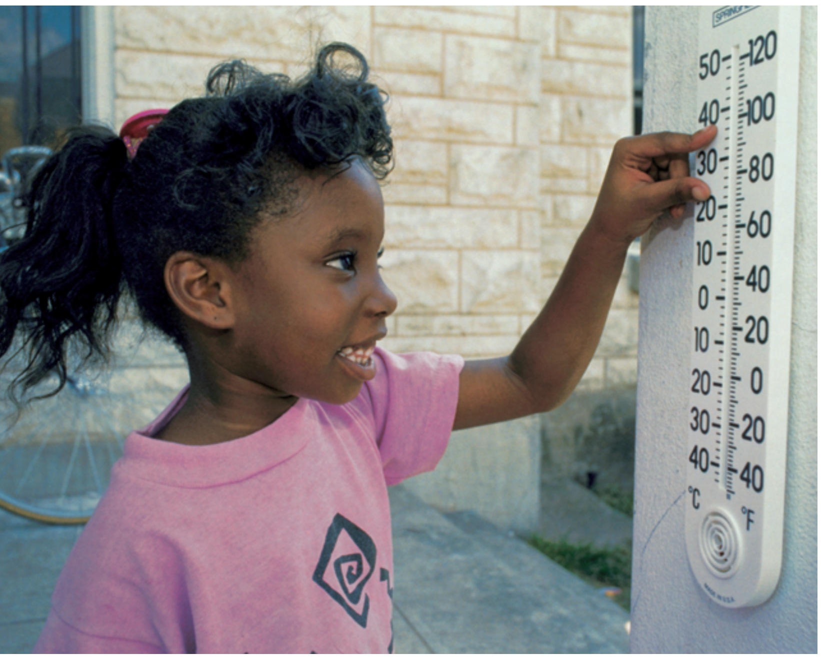
LESSON **5**

Temperature and Density



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This thermometer contains liquid. How does it work?

INTRODUCTION

Have you ever looked at a thermometer and wondered how it works? You may be surprised to learn that the thermometer was not invented until about 400 years ago. How did people measure temperature before that? Did they guess the temperature? Did they say something feels hot or cold? Thermometers are actually very easy to make from simple materials. In this lesson, you will build your own thermometer and learn something about how and why it works.

OBJECTIVES FOR THIS LESSON

Use a thermometer and discuss the purpose of its different parts.

Build a working thermometer and use it to measure temperature.

Discuss how your thermometer works and relate this to changes in the volume and density of matter.

Getting Started

1. Collect the plastic box of apparatus for your group and check the items against the materials list. Each plastic box contains a set of apparatus for each pair within your group.

SAFETY TIPS

Do not shake the thermometers. Unlike medical thermometers, the lab thermometers do not require "shaking down," and shaking increases the chances of breakage.

Always place the thermometers in a safe spot—do not let them roll off the table.

Handle the thermometers gently.

MATERIALS FOR LESSON 5

For you

- 1 copy of Student Sheet 5.1: Building a Thermometer
- 1 copy of Student Sheet 5.2: Replacing the Liquid With Air
- 1 copy of Student Sheet 5.3: Heating the Metal Strip
- 1 copy of Student Sheet 5: Engineering for Expansion

For you and your lab partner

- 1 thermometer
- 1 piece of plastic tubing mounted in a stopper
- 1 rubber stopper with single hole
- 1 20 × 150-mm test tube
- 1 250-mL beaker containing 100 mL of colored water
- 1 black permanent marker
- 1 metric ruler

Access to hot and cold water baths

2. With your lab partner, closely examine the thermometer you have been given. Discuss with your partner the purpose of the different parts of the thermometer. The following questions will help you in your discussion:

   A. Where is most of the liquid in your thermometer?

   B. What is the temperature range of your thermometer (and what units does it measure in)?

   C. What do you notice about the distances between the marks on the scale?

3. Hold the bulb of the thermometer (the red end) in your hand. Discuss the following questions with your partner:

   A. What happens to the red liquid?

   B. What temperature does it reach?

   C. What happens to the reading when you let go of the bulb and hold on to the other end of the thermometer?

   D. Why do you think the liquid in the thermometer moves?

4. Be prepared to discuss your observations and ideas with the rest of the class.

Inquiry 5.1
Building a Thermometer

PROCEDURE

1. Divide the contents of the plastic box between the two pairs in your group. How could you use the materials to build a thermometer? You have 5 minutes to discuss possible designs with your partner and draw your design on Student Sheet 5.1. Do *not* build the thermometer yet.

2. Your teacher will conduct a short brainstorming session and a discussion on thermometer design.

3. Follow the design discussed to build your thermometer.

4. Add a scale to the thermometer. This process is called calibration. To calibrate your thermometer, follow these instructions:

   A. Place the test tube end of the thermometer in the cold water bath. Let it stand for about 5 minutes.

   B. Without removing the test tube from the cold water bath, use the black permanent marker to make a mark on the plastic tubing at the water level.

   C. Use the thermometer in the water bath to record the temperature of the water bath on Student Sheet 5.1.

   D. Place the test tube in the hot water bath. Let it stand for about 5 minutes.

   E. Mark the tubing and record the temperature as before.

F. Calculate the temperature difference between the two readings you made. Write your answer on the student sheet.

G. What is the distance in millimeters (mm) between the two marks on the plastic tubing? Write your measurement under Step 3 on Student Sheet 5.1.

H. Calculate the distance on your thermometer that is equal to 1 °C.

I. Use this information to figure out where 0 °C and 100 °C will be on your thermometer.

J. Mark off the temperature scale between 0 °C and 100 °C in 5 °C intervals. Label these intervals every 10 °C.

5. Once you have built and calibrated your thermometer, test it by measuring room temperature. Allow time for your thermometer to reach room temperature. What reading did your thermometer give for room temperature? Write your answer on the student sheet.

6. Measure room temperature with the laboratory thermometer. What reading did the laboratory thermometer give? Write your answer on the student sheet.

7. Answer the following questions on your student sheet: How accurate is your thermometer compared with the laboratory thermometer? How quickly does your thermometer respond to temperature changes? Is it quicker, slower, or the same as the laboratory thermometer? When the temperature increases, what happens to the volume of water in your thermometer? When the temperature increases, do you think the mass of water in your thermometer changes? If you decreased the size of the thermometer bulb, how would the accuracy and the response time of your thermometer be affected? How could you improve the design of your thermometer to make it more accurate?

Inquiry 5.2
Replacing the Liquid With Air

PROCEDURE

1. Redesign your thermometer so that it uses air. Here are some problems to think about:

A. How will you stop the air from escaping?

B. How will you measure the distance the air moves up the column?

2. Draw your design on Student Sheet 5.2. After a short class discussion, build your thermometer and try to calibrate it.

3. Answer the following questions on the student sheet. What problems did you encounter when calibrating your air-filled thermometer? How did the response of your air-filled thermometer compare with that of your liquid-filled one?

Inquiry 5.3
Heating the Metal Strip

PROCEDURE

1. Your teacher will pass around a metal strip. What do you notice about both sides of the strip?

2. What do you think will happen to the metal strip when it is heated? Write your answer on Student Sheet 5.3.

3. Observe what happens to the strip as your teacher heats it. Answer the following question on the student sheet: What did you observe when the strip was heated?

4. Observe the strip after it cools. Answer the following question on the student sheet: What happens to the strip after it cools?

5. Observe what happens to the strip when your teacher heats the other side of it. Answer the following questions on the student sheet: What did you observe when the strip was heated on the other side? Why do you think the strip behaves this way?

REFLECTING ON WHAT YOU'VE DONE

1. Answer the following questions in your science notebook:

   A. What do these three inquiries tell you about how the volume of matter is affected by temperature?

   B. How does the change in the volume of the air differ from the change in the volume of the liquid?

   C. How does this change in volume affect the density of solids, liquids, and gases?

   D. When measuring the density of a substance, why is it important to record the temperature of the substance?

   E. Are there any other uses for the expansion and contraction of matter?

   F. Could expansion or contraction cause problems? (You may wish to look at the reader about the Trans-Alaska Pipeline on pages 52–55 to help you answer this question.)

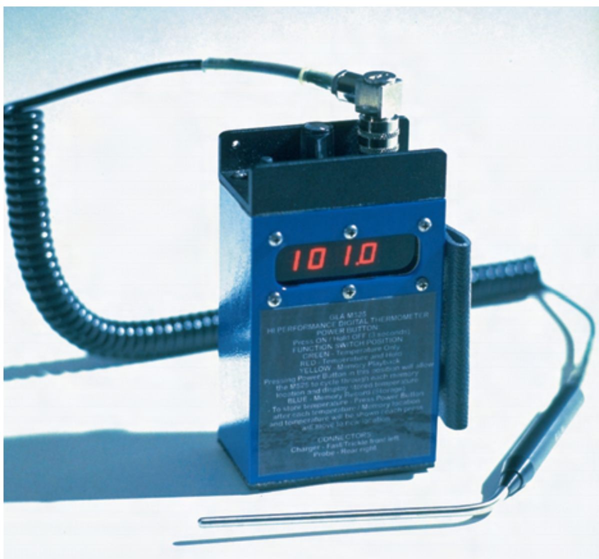
2. Read "Changing Temperature, Changing Density", on page 43.

CHANGING TEMPERATURE, CHANGING DENSITY

Most matter increases in volume when it gets hotter. For example, if an iron rod is heated, it will get longer and fatter and its density will decrease. This happens because the mass of the rod stays the same, but its volume increases. The increase in the volume of matter with increasing temperature is called expansion. When cooled down, most matter decreases in volume and increases in density. This decrease in volume is called contraction.

A few substances behave differently when heated or cooled. Water is one such substance. When water approaches freezing, it expands and becomes less dense, which is why water pipes sometimes burst when they freeze and why icebergs float.

GLA AGRICULTURAL ELECTRONICS

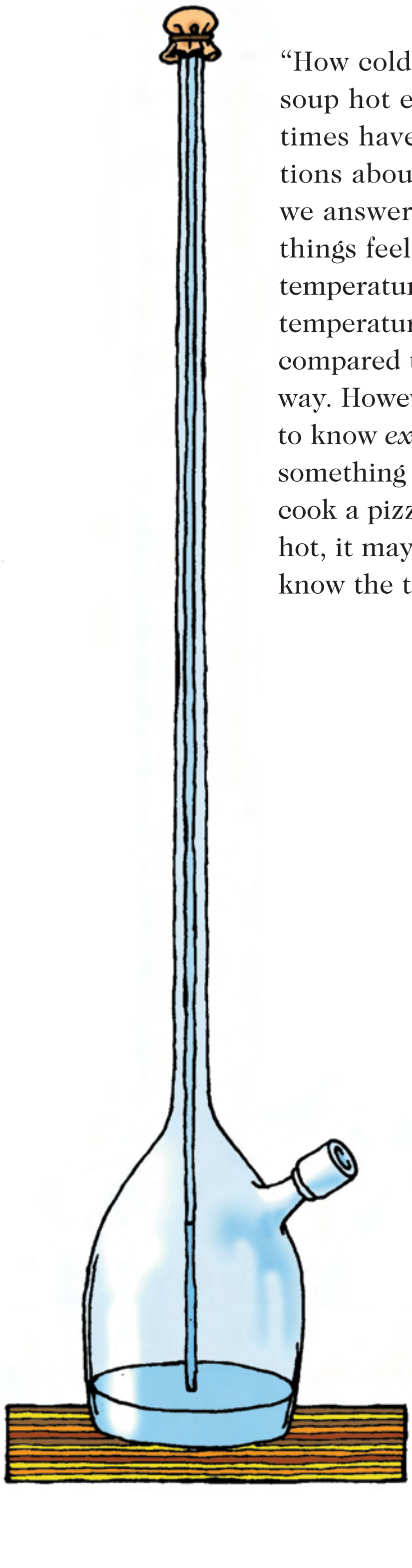


This horse thermometer has a digital readout. Veterinarians can use it in conjunction with a computer. It does not use changing density to measure temperature. Do you know how it works?

CORBIS/LOWELL GEORGIA

Some thermometers use bimetal strips to measure temperature. In this lesson, you may get some ideas about how these thermometers work.

MEASURING TEMPERATURE BY DEGREES



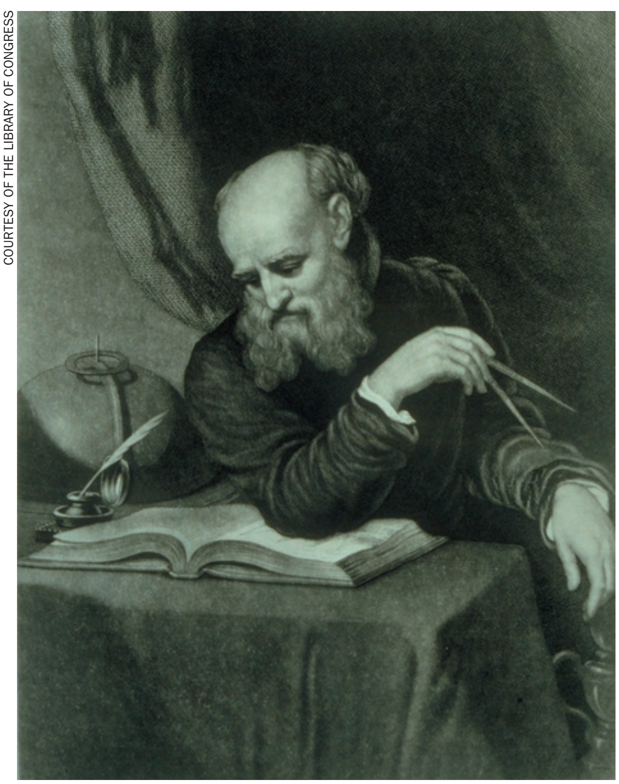
"How cold is it outside?" "Is your soup hot enough?" How many times have you been asked questions about temperature? Usually, we answer them according to how things feel to us. We compare temperatures to our own body temperature. People have always compared temperatures in this way. However, sometimes you need to know *exactly* how hot or cold something is. For example, if you cook a pizza in an oven that is too hot, it may burn—so you need to know the temperature of the oven.

A thermoscope built to one of Galileo's designs. Thermoscopes were used to compare temperatures but had no standardized scale.

About 400 years ago, some scientists began to tackle the problem of measuring temperature. Galileo was one of the first.

He made a thermoscope. This was a device that could be used to compare temperatures. Look at the picture of the thermoscope. Can you figure out how it worked?

It took another scientist, Olas Roemer, a Dane who was interested in astronomy and meteorology, to come up with a way of comparing temperatures measured with different devices. In 1701, Roemer calibrated his temperature-measuring devices according to the temperatures of ice water and the human body. He had made the first thermometer.



Galileo built some of the earliest thermoscopes, which are thermometers without scales.

Roemer invented the first useful temperature scale.

In 1742, Anders Celsius invented the Celsius (or centigrade) scale.

William Thomson started his temperature scale with the lowest possible temperature.

Another scientist, this time from Holland, borrowed Roemer's ideas. His name was G. Daniel Fahrenheit. Fahrenheit altered Roemer's scale. He used the melting point of a salt-and-water slush as his zero point and the human body temperature as his high point. He divided the space between the two points into 96 degrees. The scale was later adjusted so that its calibration points were at 32 °F for ice melting and 212 °F for water boiling. On the adjusted scale, human body temperature became 98.6 °F. The new scale was named after Fahrenheit and is still used today.

About 30 years later, in 1742, another scientist, Anders Celsius from Sweden, came up with a new scale. Celsius designated the melting point of ice as 100 °C and the boiling point of water (at sea level) as 0 °C. After Celsius's death, the scale was reversed so that the melting point of ice became 0 °C and the boiling point of water (at sea level) became 100 °C. This scale, called the Celsius (or centigrade) scale, was popular because it used two temperatures that most people easily understand. It's now used all around the world. This scale has one big problem. All temperatures below zero become negative numbers. Can you really have a negative temperature? Wouldn't it be better to start a scale at the lowest possible temperature and work your way up?

About 100 years later, in 1848, British physicist William Thomson could see the advantage of just such a scale. By that time, work done by Thomson and other scientists on how energy behaves in the universe led him to develop a scale that placed the absolute lowest possible temperature at zero. This temperature is the same as –273 °C and is called absolute zero. An object at absolute zero contains no heat energy. Thomson borrowed the divisions on Celsius's scale and made the melting point of ice 273 degrees. What happened to the Thomson scale? It is still used by scientists around the world, who consider it to be the most useful temperature scale.

Thomson was such a clever scientist and inventor that the British government made him a lord and gave him the title Lord Kelvin. So his scale became the Kelvin scale, and temperature is measured in kelvins (abbreviated as K). □

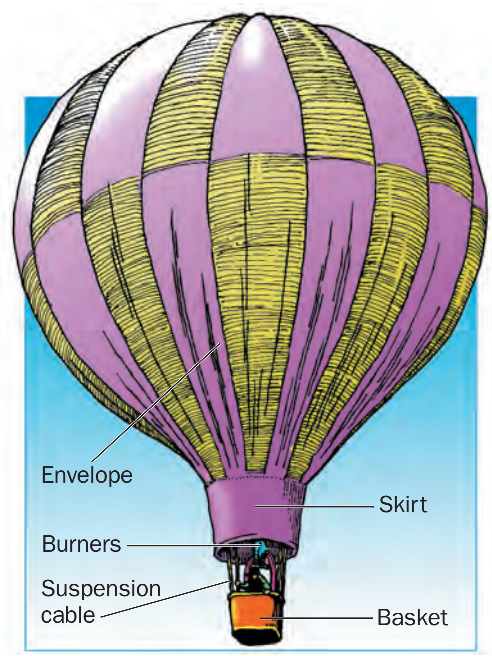
JUST A LOAD OF HOT AIR

Hot air balloons can be made into many fun shapes. But why do they need to be so big?

Just a load of hot air! That's what you will find inside a hot air balloon. But why does hot air help a balloon rise? Hot air balloons rely on the fact that the density of air decreases as it gets hotter. A gas burner, mounted above a balloon's basket, is used to heat the air inside the balloon. As the air heats, it increases in volume, or expands. You already know that density is equal to mass divided by volume. So what happens if the volume of the air inside a balloon increases while the mass of the air stays the same? The density of the air in the balloon decreases. When the average density of the balloon (including the burner, basket, and passengers) becomes less than the density of the surrounding air, the balloon begins to rise. It floats in the air.

The balloonist can alter the height of the balloon by switching the burner on and off. If the burner is turned off, the air inside the balloon cools. As the air cools, its volume decreases, it becomes denser, and the balloon goes down. The balloonist can also let some of the hot air out of the top of the balloon to make the balloon go down. If the burner is turned on, the air in the balloon becomes hotter. The air takes up more volume, becomes less dense, and the balloon rises.

The first free flight of a hot air balloon was in 1783, when the Montgolfier brothers sent a sheep, a duck, and a rooster into the air in a balloon made from linen. A few weeks later, in the first manned free flight, two Frenchmen, using burning straw as a heat source, piloted a Montgolfier balloon about 5 miles across Paris.



The hot air balloon rises because its average density is less than the surrounding air.

COURTESY OF SAN DIEGO AEROSPACE MUSEUM

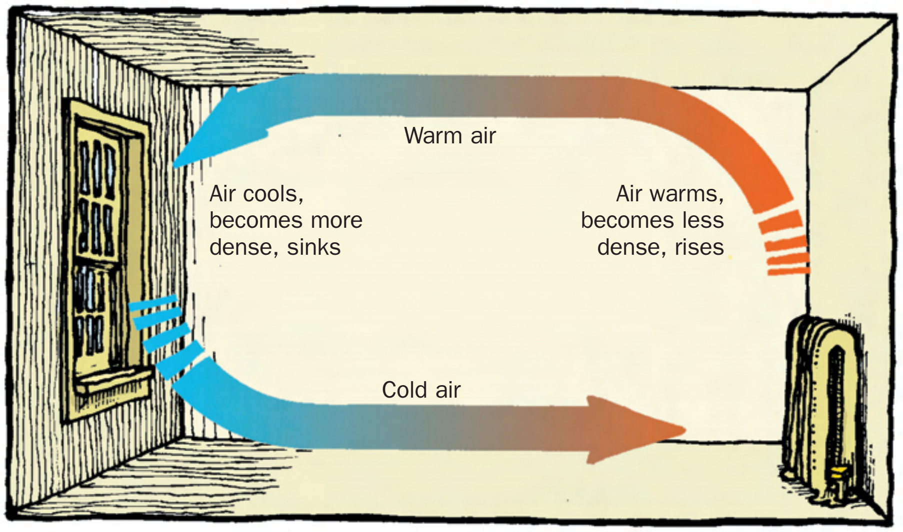
This is a scale model of the balloon used for the first manned balloon flight. The balloon reached a height of almost 1000 meters and stayed aloft for 25 minutes.

Today, most hot air balloons are made from ripstop nylon and use propane gas burners instead of straw. The average hot air balloon is as tall as a seven-story building, is about 20 meters across at the widest part, and is big enough to carry four adults. Hot air balloons can be built in many shapes. ☐

QUESTION

How does a balloon pilot use density to control the altitude of a balloon?

Density Creates Currents



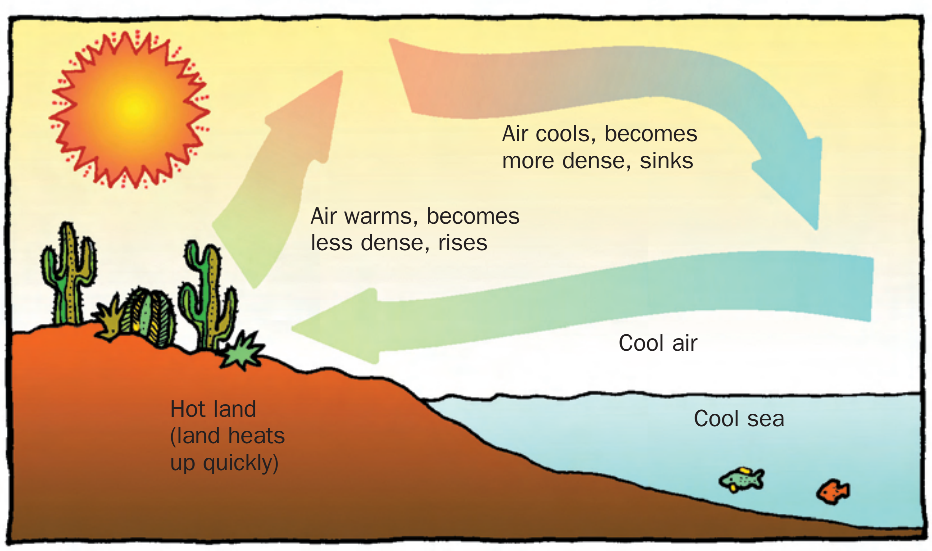
A convection cell can occur in a room.

How do changes in density move matter? This movement involves a process called convection. To understand how convection works, imagine a room in a house, like the one shown in the picture above.

One side of the room has a heater; on the opposite wall is a window. On a cold winter day, when the heat is on, air near the heater will warm up. What happens to hot air? It expands, becomes less dense, and rises. On reaching the ceiling, it is pushed along by more hot air rising behind it. The heated air starts to cool down the farther it drifts from the heater, and this process is speeded up when it meets the cold window. As the air cools, it becomes more dense, sinks to the floor, and eventually completes a circuit of the room. A circular convection current is set up. Circular currents like this are called convection cells.

Convection currents like this also take place in the atmosphere (see the picture below).

We encounter these convection currents as wind. Where do you think the heat energy for these convection currents comes from? Real winds are more complex than what is shown in the picture, but all winds are created by changes in density brought about by temperature differences. How do you think the winds shown in the picture would be different at night?



A convection cell can also occur in the atmosphere.

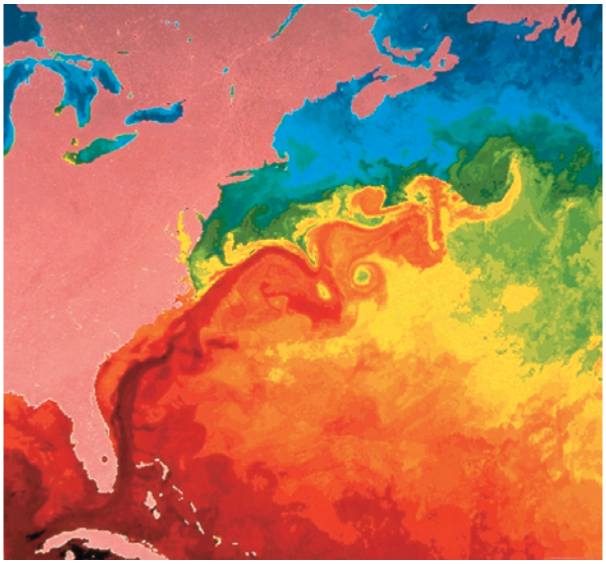


IMAGE COURTESY OF NASA/GODDARD SPACE FLIGHT CENTER AND ORBITAL IMAGING CORPORATION (ORBIMAGE)

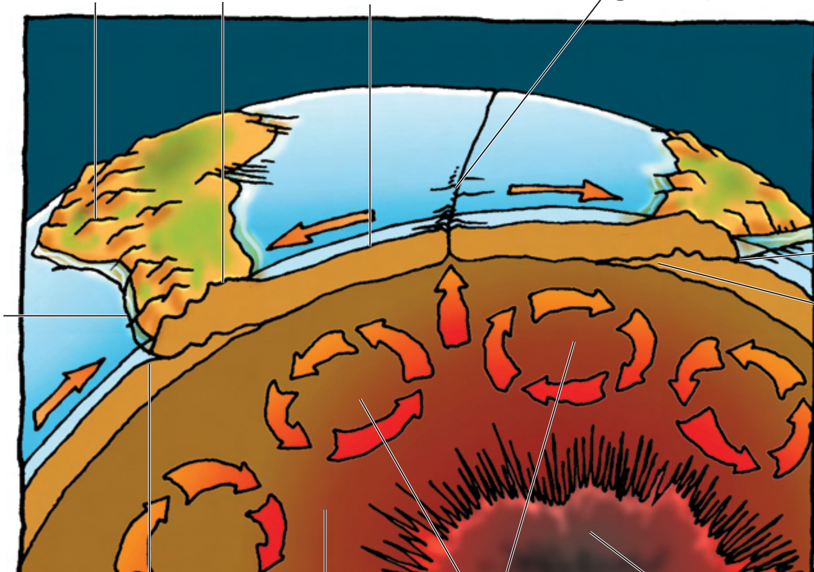
The Gulf Stream is an ocean current that is driven, in part, by convection. It carries warm water from the tropics toward the North Pole.

Convection works in liquids as well as in gases. Ocean currents have several different causes, many of which are due to changes in density. Some ocean currents are convection currents (see the picture on the left).

Under the tropical sun, water at the equator warms up. At the cold poles, seawater cools down and sinks. Convection cells are set up with warm water moving along the surface to the poles and deep cold water flowing toward the equator. Changes in density, caused by changes in salinity (the amount of salt in the water), are also important in the formation of ocean currents. Ice formation near the poles leaves salt behind in the remaining water. This denser, more saline water sinks, creating its own density-driven currents. Surface winds also set surface currents into motion.

Moving and Making Mountains

Convection currents can move or split whole continents. Radioactive substances deep within the Earth provide the heat that drives these currents (see the picture below illustrating how these convection cells work).

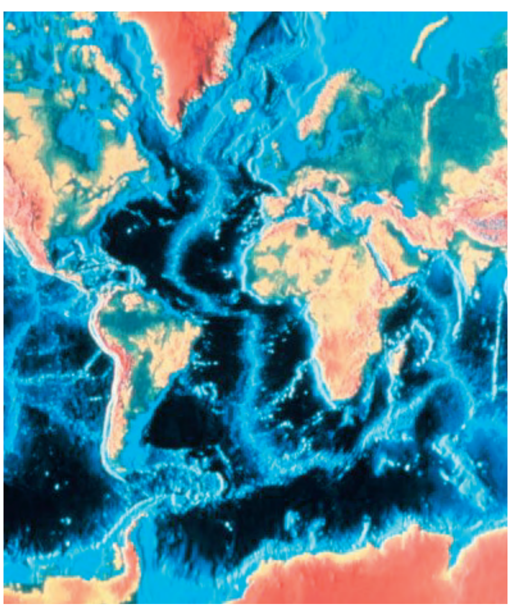


Convection cells exist within the Earth.

Earth's surface is made up of a series of giant plates that fit together like a moving spherical jigsaw. These plates can be made from two types of crustal material: dense oceanic crust and comparatively less dense continental crust. The hot rocks deep in the mantle behave like a soft plastic. These warm, less dense rocks move up, pushing aside rock that lies on the surface. These convection currents create some of the mountain ridges found on the ocean bed. The Mid-Atlantic Ridge is one example. Sometimes these ridges emerge at the surface of the ocean as islands.

Convection currents in the Earth produce volcanoes, like this one near Iceland in the North Atlantic.

Eventually this volcano formed an island called Surtsey.



Surtsey is part of a mountain system, formed as a result of convection currents, that extends under the Atlantic Ocean.

ANNE B. KEISER

Great ranges of fold mountains are formed where plates collide. Mount Everest, the highest mountain in the world, is in the Himalayas of Nepal. These mountains are being formed as the plate carrying India collides with the plate carrying Asia.

As plates expand, they push against other plates. When plates that consist of two pieces of continent push against one another, they may buckle up along their boundaries to form great fold mountains (see the photo of Mount Everest). They may also slide past one another, as at the famous San Andreas fault in California.

Earthquakes can occur as the plates slide past one another or build mountains. If a plate of more dense oceanic crust pushes against less dense continental crust, what do you think happens? The more dense ocean crust sinks down to create ocean trenches. Evidence for this process is provided in the form of the volcanoes and earthquakes that are caused by all this activity.

Why is density important? Changes in density drive many of Earth's processes. Next time you climb a mountain or hear about an earthquake or a tornado, think about how density and density changes have an impact on human lives! ☐

QUESTION

Big birds such as vultures and hawks can often be seen gliding around and around over big parking lots on sunny days, without even flapping their wings. Why?

The Trans-Alaska Pipeline: Meeting Nature's Challenges

Trans-Alaska Pipeline: Facts and Figures

- The pipeline is 1287 kilometers long. Each piece is 127 centimeters in diameter.
- The pipeline crosses 34 major rivers and streams and 3 mountain ranges.
- Construction was started in 1973 and completed in 1977. The cost was $8 billion.

The Trans-Alaska Pipeline (in red) stretches from Valdez to Deadhorse.

It was 1968, and the United States was concerned about its oil supply. With war brewing in the Middle East and an oil embargo threatening, where would the United States get the petroleum it needed? How could the country become less dependent on oil imports in the years ahead?

Just when concerns were getting serious, geologists discovered the largest oil field in this country—in Prudhoe Bay on the northern slope of Alaska. Part of the problem was solved.

But during the winter, the waters of Prudhoe Bay are frozen solid. For much of the year, they cannot be reached by seagoing oil tankers. How could those billions of gallons of oil be transported to the lower United States? The answer: Build a pipeline!

The people who took on this problem

PHOTO COURTESY ALYESKA PIPELINE SERVICE COMPANY

Fiberglass insulation is being wrapped around the pipeline to reduce heat loss.

would find themselves involved in one of the most difficult engineering challenges of this century. To solve it, they had to focus on three features of the Alaskan territory: permafrost, earthquakes, and temperature extremes.

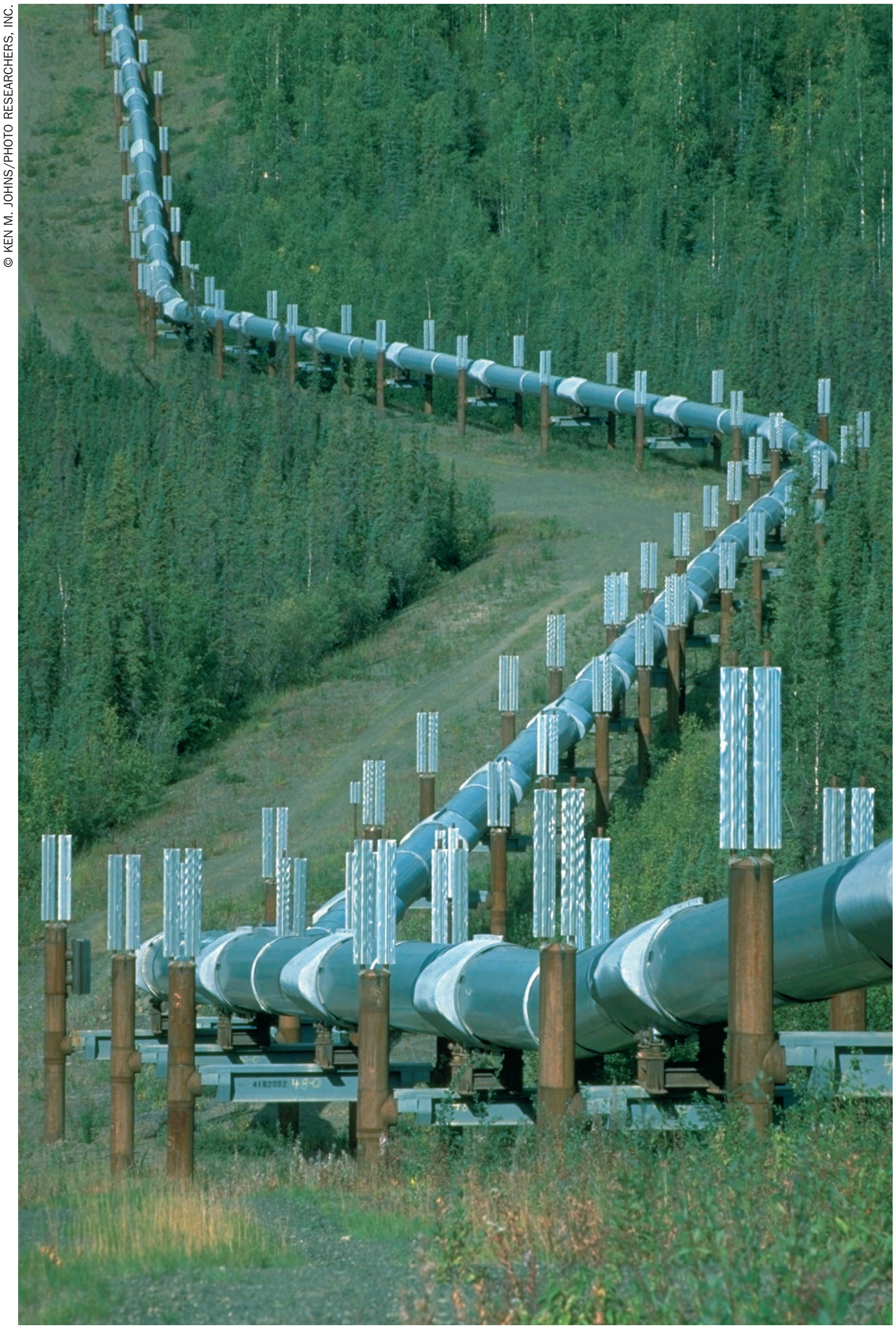
Watching Out for Permafrost

At first, the engineers assumed that the pipeline would be buried underground. That's how most pipelines are built, after all.

But no one had ever built a pipeline in a place like Alaska, where it gets so cold that in many parts of the state, the subsoil is permanently frozen. This deep soil, which never thaws, is called permafrost.

Planners realized that the pipeline couldn't be buried in the permafrost, because the heat of the oil could cause the icy soil to melt. If the icy soil melted, the pipe would sag and it might leak. In winter, the soil around the pipe would freeze again. This freeze-thaw cycle could cause the pipe to move enough to cause serious damage.

To avoid these complications, the engineers made an important decision: About one-half of the pipeline (about 700 kilometers) would have to be built above ground. They supported the pipe with refrigeration posts that are topped with aluminum radiators. The posts conduct heat away from the soil. The pipeline is also wrapped in 10 centimeters of fiberglass insulation. Both of these measures help to keep the permafrost solid.



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The pipeline was mounted on posts above the frozen ground. The aluminum radiators on top of the posts conduct heat—lost from the pipeline—away from the soil. The zigzag in the pipeline allows it to expand and contract without breaking.

Blowing Hot and Cold

A second challenge was Alaska's temperature, which ranges between –60 °C and 35 °C. Because the metals from which the pipeline is made expand and contract with changes in temperature, the pipeline had to be built to accommodate changes in length. The engineers estimated that a 304-meter segment of pipeline could shrink by as much as 0.3 meter in the coldest weather and expand by an equal amount during the warmest season. That doesn't sound like much of a change, unless you remember that the pipeline is nearly 1500 kilometers long! If the pipeline were straight, even a small change in each segment of the pipeline would be disastrous. The pipeline would either snap if it contracted too much or buckle if it expanded.

To prevent the pipeline from breaking, the designers used a zig-zag configuration. These bends help relieve the effect of contraction and expansion.

Accounting for Earthquakes

As if these extreme temperatures weren't enough, engineers had to deal with another big problem: earthquakes. Earthquakes are fairly common in Alaska. In fact, the largest earthquake ever to occur in the United States (measuring 9.2 on the Richter scale) took place in southern Alaska. The engineers had to build a pipeline that could survive such an event intact.

They designed a two-part system of "shoes" and "anchors" that hold the pipeline in place at weak areas (faults) where earthquakes have occurred, yet allow it to move enough so that it does not fall off its supports if the ground moves. At the Denali fault zone, where earthquake activity has been heavy, the pipeline is designed to move up to 6 meters side to side and 1.5 meters up and down. ☐

QUESTIONS

1. How did engineers overcome the challenge of a 95 °C temperature range when designing the Trans-Alaska Pipeline?
2. What is the difference between conduction and radiation? Use a dictionary or other references to help you answer this question.