Chapter 10

The kinetic molecular theory explains the transfer of thermal energy.

When you feel the steely bite of winter rain or the warmth of sunlight, thermal energy is being transferred. The transfer of thermal energy is also behind the gentlest summer breeze and the most violent hurricane.

In this chapter, you will investigate how thermal energy is transferred. You will discover how the atmosphere captures and transports the thermal energy that sustains life on Earth—and sometimes threatens its existence. You will also learn how the atmosphere, like a blanket, protects Earth from deadly cold as well as radiation from space.

What You Will Learn

In this chapter, you will

- **define** heat, thermal energy, and atmospheric pressure
- **describe** Earth's sources of thermal energy
- **describe** how energy transfer affects the atmosphere
- **identify** weather conditions caused by high or low atmospheric pressure

Why It Is Important

Understanding the process of thermal energy transfer helps us to understand what causes the weather and how to better predict it.

Skills You Will Use

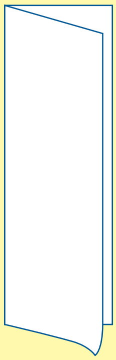
In this chapter, you will

- **observe** the effects of atmospheric pressure
- **measure** temperature and atmospheric pressure
- **explain** and **model** the transfer of thermal energy
- **graph** atmospheric temperatures and experimental results

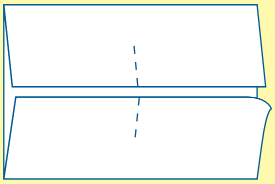
FOLDABLES™ Reading & Study Skills

Make the following Foldable to take notes on what you learn in Chapter 10.

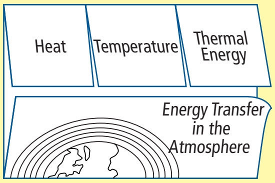
STEP 1 Use a sheet of 28 cm x 43 cm paper to create this modified shutterfold. **Fold** it as if you were going to make a hot dog, but instead of creasing the paper, **pinch** it to show the midpoint.



STEP 2 **Fold** the outer edges of the paper to meet at the pinch, or midpoint, forming a shutterfold.



STEP 3 **Hold** the shutterfold horizontally and **cut** the upper tab into thirds. Leave the bottom tab whole. **Label** the top three tabs as shown.



Record information, define key terms, and provide examples beneath the tabs. Glue or draw a half section image of Earth on the bottom tab showing the five levels of the atmosphere to create a quick visual reference. Beneath the tab, record information as you progress through the chapter.

10.1 Temperature, Thermal Energy, and Heat

The kinetic molecular theory explains that particles in matter are in constant motion. Matter has thermal energy due to the kinetic and potential energies of its particles. Heat is the amount of thermal energy transferred from a warmer area to a cooler one. Heat transfer occurs by collisions between particles (conduction), the movement of fluids (convection), or the movement of electromagnetic waves (radiation).

Words to Know

conduction
convection
electromagnetic radiation
heat
kinetic energy
kinetic molecular theory
temperature
thermal energy

Did You Know?

In outer space, far away from any planets, stars, or meteors, there are very few particles. However, even these few particles vibrate with kinetic energy. The Big Bang theory is one explanation for this phenomenon. Scientists suggest that the low level of energy in outer space is left over from the Big Bang, the expansion of the universe that began billions of years ago.

You have probably heard expressions like “this classroom is freezing,” “this soup is too hot,” or “it feels warm outside.” All of these expressions may seem to refer to the same idea. However, each relates to a different concept: temperature, thermal energy, or heat. To understand the differences among these concepts, it is important to review the kinetic molecular theory.

As you may have learned in earlier science courses, the **kinetic molecular theory** explains that all matter is composed of particles (atoms and molecules). These particles move constantly in random directions. **Kinetic energy** is the energy of a particle or an object due to its motion. When particles collide, kinetic energy is transferred between them, much as a bowling ball transfers energy to the bowling pins it hits.

The particles of a substance are bonded together differently depending on the state of the substance. When the substance is in a solid state, the particles are very close together and vibrate slowly (Figure 10.1). When the same substance is in a liquid state, the particles are farther apart. When the same substance is in a gas state, the particles spread even farther apart. The particles of a substance move faster when the temperature of the substance increases.

Figure 10.1 Particles in a solid (right) are strongly attracted to one another. Particles in liquids (left) and gases (middle) move freely and are spread farther apart.

10-1A Heat It Up

Find Out ACTIVITY

According to the kinetic molecular theory, the more kinetic energy that particles have, the faster the particles will move and the more they will spread apart. In this activity, you will examine the relationship between particle motion and temperature.

Safety

- Use caution when handling the lamp as the light bulb will become very hot.

Materials

- alcohol thermometer
- 250 mL beaker
- cold water
- lamp with 100 W incandescent bulb

What to Do

1. Read the thermometer.
2. Fill the beaker with 100 mL of cold tap water. Use the thermometer to measure the temperature of the water.
3. Set up the lamp so that the light will shine directly on the beaker of water. Turn on the lamp.
4. Hold the thermometer in the beaker of water for at least 5 min. Observe the thermometer during this time.
5. Clean up and put away the equipment you have used.

What Did You Find Out?

1. State what you saw happening to the liquid in the thermometer:
   (a) when you took the first temperature reading
   (b) while the light was shining on the beaker of water
2. Explain your observations above using the kinetic molecular theory.
3. What made the temperature of the water change?
4. Why did it take time to get a temperature reading of the water?

Temperature

Even within a pure substance, in which the particles are identical, the kinetic energy of the particles will vary. The particles travel at different speeds and in different directions. **Temperature** is a measure of the average kinetic energy of all the particles in a sample of matter. A cup of hot chocolate feels hot because the average kinetic energy of its particles is higher than the average kinetic energy of the particles in your hand. As the particles' average kinetic energy increases, the temperature of a solid, liquid, or gas will also increase. For example, particles in a glass of cold water move slower and have less kinetic energy than particles in a cup of hot water (Figure 10.2).

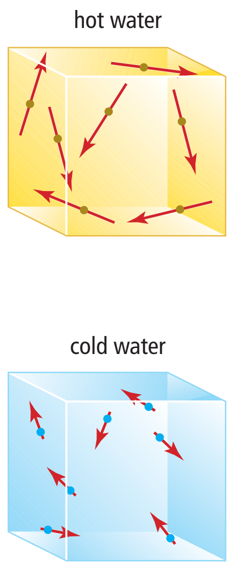


Figure 10.2 The dots represent water molecules. The arrows show how fast the water molecules are moving and in what direction.

Temperature scales

Three different number scales are used to measure temperature: Fahrenheit, Celsius, and Kelvin. The Fahrenheit scale was designed by the German-Dutch physicist Daniel Gabriel Fahrenheit (1686–1736) and has been used since 1724.

The Celsius scale was named after its inventor, the Swedish astronomer Anders Celsius (1701–1744). First used in 1745, the Celsius scale was later included in the metric system and is now used around the world. The Celsius scale is based on two fixed points: the freezing point of pure water (0°C) and the boiling point of pure water (100°C).

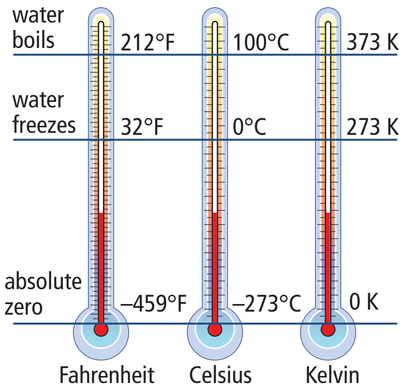


Figure 10.3 The temperature scales

In 1848, William Thompson (1824–1907) of Scotland proposed a temperature scale based on absolute zero, the temperature at which particles would have no kinetic energy. Thompson was later given the title Lord Kelvin, and so his scale is known as the Kelvin scale. Figure 10.3 gives the values of absolute zero and the freezing point and boiling point of water using the three different temperature scales.

Reading Check

1. What is the kinetic molecular theory?
2. Define temperature.
3. Name three temperature scales.

Word Connect

The word "kinetic" comes from the ancient Greek word *kinetikos*, meaning to put in motion.

Thermal Energy

Thermal energy is the total energy of all the particles in a solid, liquid, or gas. The more kinetic energy a solid, liquid, or gas has, the more thermal energy it has. A hot bowl of soup, for example, has more thermal energy when it is first served than after it cools. Since thermal energy includes the energy of all of the particles in a sample of matter, a large bowl of soup would have more thermal energy than a small one. In fact, a swimming pool of lukewarm water would have more thermal energy than a small cup of hot tea.

Kinetic energy is not the only energy associated with moving particles (Figure 10.4). **Potential energy** is the stored energy of an object or particle, due to its position or state. An example is the gravitational attraction between Earth and a textbook you are holding. As you lift the textbook, its gravitational potential energy increases. The lower you hold the book, the less gravitational potential energy it has. Similarly, there are attractive electrical forces between atoms and molecules. The pull of these attractive forces gives particles potential energy.

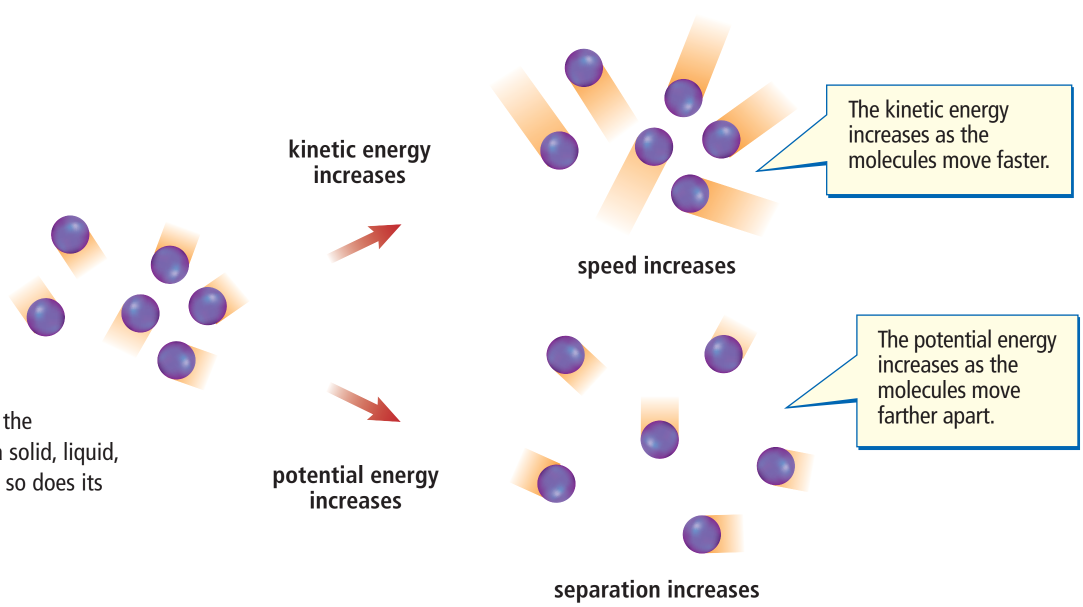


Figure 10.4 As the temperature of a solid, liquid, or gas increases, so does its thermal energy.

Heat

The terms "heat," "temperature," and "thermal energy" are often used as if they have the same meaning, but they do not. **Heat** is the amount of thermal energy that transfers from an area or object of higher temperature to an area or object of lower temperature. Consider how heat is used to cook an egg. Heat flows from the hot stove element to the frying pan and then to the egg. As the egg gains thermal energy, the kinetic energy of the egg's atoms and molecules increases, and so does its temperature. The egg heats up and cooks (Figure 10.5). Heat can similarly flow within and between large systems, such as the oceans and the atmosphere.

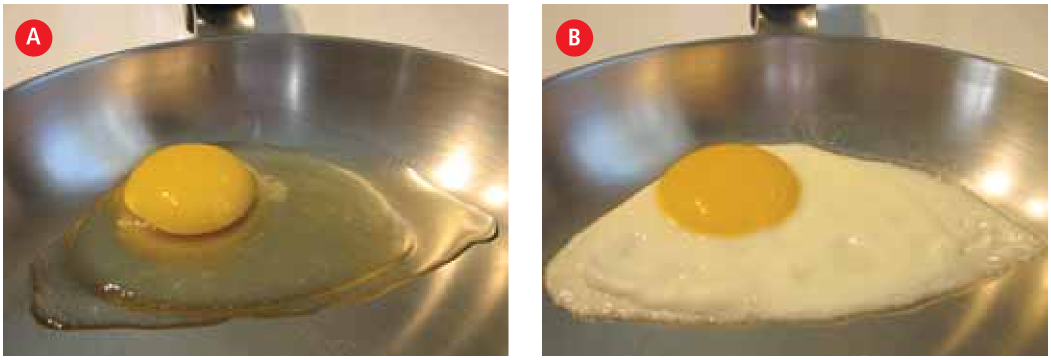


Figure 10.5 Heat transfers from the frying pan to the egg.

Reading Check

1. What term describes the total amount of energy of a solid, liquid, or gas?
2. How does temperature relate to thermal energy?
3. What is heat?

Heat Transfer

Heat can be transferred in three ways: conduction, convection, and radiation. Figure 10.6 shows a pot of boiling water on a stove. This figure illustrates all three types of heat transfer. The next three pages will describe the types of heat transfer in more detail.

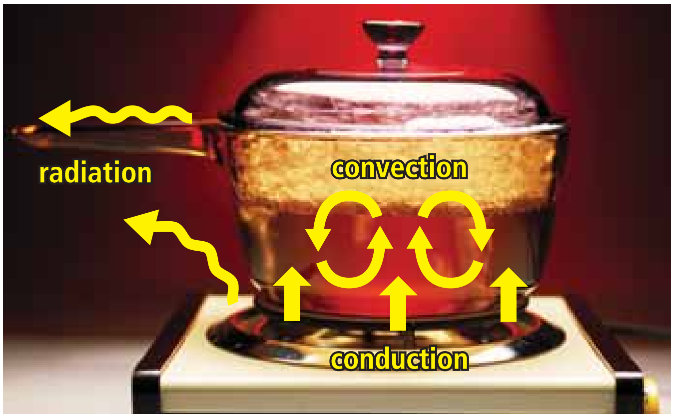


Figure 10.6 The stove element heats the pot and the pot heats the water by conduction. Water circulating in the pot transfers heat by convection. Near the stove, the air would feel warm due to heat transfer by radiation.

Conduction

Conduction is the transfer of heat from one substance to another or within a solid by direct contact of particles. Conduction transfers heat from matter with a higher temperature and greater kinetic energy to matter with a lower temperature and lower kinetic energy. This process explains why a metal spoon left in a pot of boiling water becomes hot to touch. The stove element heats the pot, which in turn heats the water. Heating increases the kinetic energy of the water molecules, which collide with particles in the spoon. The collisions transfer kinetic energy to the slower-moving particles of the spoon. As the collisions between particles continue, heat transfers to the spoon, making it feel hot.

Most materials can transfer heat by conduction, but they transfer it at different rates. Thermal conductors are materials that transfer heat easily. Metals, for example, are good thermal conductors. Materials that do not transfer heat easily are called insulators. Air, snow, wood, and Styrofoam® are examples of insulators (Figure 10.7).

Suggested Activity

Conduct an Investigation 10-1B on page 432

Did You Know?

On a cold winter day, if you touch anything metal, it feels very cold. However, the metal is not actually colder than the surrounding air. Most metals are excellent conductors and rapidly conduct thermal energy away from your hand. Your brain interprets the transfer of thermal energy to the metal as the sensation of cold.

Figure 10.7 Aluminum is a good thermal conductor (A). Styrofoam® is a good thermal insulator (B).

Reading Check

1. What term describes the transfer of heat by direct contact between particles?
2. What is the direction of heat transfer: higher temperature areas to lower temperature areas, or lower temperature area to higher temperature areas?
3. What is a conductor?
4. What is the term for a substance with low conductivity?

Convection

Liquids and gases are fluids. **Fluids** are substances in which the particles can flow freely. This characteristic allows for a second type of heat transfer, called convection. **Convection** is the transfer of heat within a fluid and with the movement of fluid from one place to another. Unlike conduction, convection transfers matter as well as heat.

The movement of liquid in a lava lamp occurs by convection. Melted rock under Earth's surface and clouds in the sky also move by convection (Figure 10.8).

internet connect

The horizontal transfer of heat in a fluid is called advection. To find out how ocean currents transfer heat by advection go to **www.bcscience10.ca**.

Figure 10.8 Convection currents are responsible for heat transfer in the lava lamp (A) and the lake of melted rock (B). Convection currents also produced the storm cloud (C).

Convection can be explained by the kinetic molecular theory. As particles move faster and their kinetic energy increases, they move farther apart. As the particles in a fluid move farther apart, the fluid itself expands and its density decreases. As you may have learned in earlier science courses, density is mass divided by volume. Therefore, if the mass of a sample of material remains the same but the volume increases, the density decreases.

Heating the air in a hot air balloon causes the air to expand. Because the air expands, it becomes lighter and the balloon can rise off the ground. Similarly, in a bubbling pot of water on the stove, the warmer water at the bottom of the pot rises because it is less dense than the surrounding water. At the surface, the water cools, contracts, and sinks—only to be reheated and recirculated. The movement of the water, caused by continuous cycling of heating, cooling, and reheating, is called a convection current. A **convection current** is the movement of a fluid caused by density differences.

Convection is used in a variety of household tools. Convection ovens use convection currents to transfer heat to food. Some home-heating systems also use convection (Figure 10.9). For example, a hot air furnace supplies warm air to a room through hot air vents. The warm air rises and then cools as it loses heat to surrounding air. The cooled air contracts and sinks, only to be reheated or replaced by incoming warm air. The convection current can therefore be used to warm an entire room.

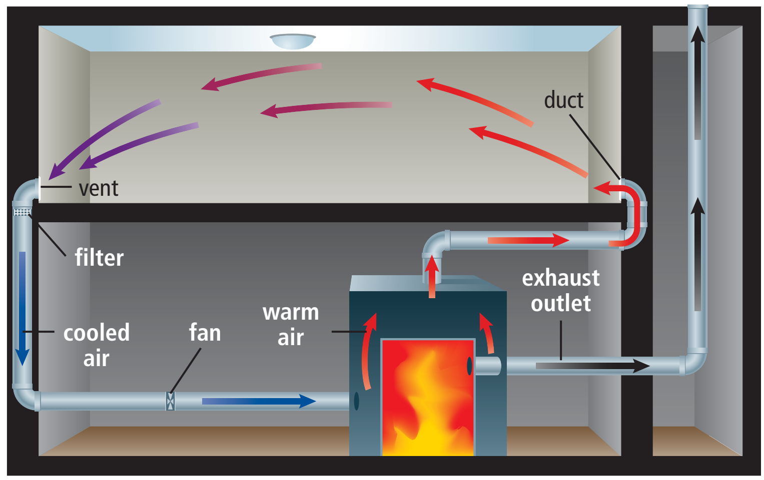


Figure 10.9 Hot air furnaces rely on convection currents to transfer heat throughout a room.

Suggested Activity

Conduct an Investigation 10-1C on page 433

Reading Check

1. What is the term for matter that can flow freely?
2. Does convection transfer heat or both heat and matter?
3. What happens to the density of an uncontained fluid when it is heated?
4. What is a convection current?

Radiation

Without heat transfer from the Sun, life on Earth would not exist as we know it. But how can heat be transferred through space, where particles are spread so far apart that there is little chance they will collide? **Electromagnetic radiation**, is the transfer of energy by waves travelling outward in all directions from a source. Electromagnetic waves radiate (travel by radiation) through space even though there is no matter there. **Radiant energy** is the energy carried by electromagnetic waves.

The only electromagnetic radiation we can see is visible light. Most of the electromagnetic spectrum is invisible to the unaided human eye. However, if you stand too close to a campfire, you will experience the reality of **infrared radiation**, also known as heat radiation (Figure 10.10). When you stand in sunlight, your skin feels warm due to solar radiation, the transfer of radiant energy from the Sun (Figure 10.11 on the next page). **Solar radiation** is made up of visible light as well as infrared and other types of radiation (Figure 10.12 on the next page).

Figure 10.10 Your body is a source of infrared radiation.

Any material with a temperature greater than absolute zero radiates some heat, including bicycle tires, baby diapers, ice cubes, oceans, and even you. Some materials transfer more heat than others. As you will read in Chapter 12, volcanic eruptions are a result of the release of thermal energy under Earth's surface. Scientists think that a great deal of thermal energy was stored as Earth formed from the build-up of dust into a bigger and bigger rocky lump. Some of this thermal energy was released over time. Residual thermal energy from Earth's formation continues to heat the planet. The decay of radioactive elements underground is another source of thermal energy on Earth.

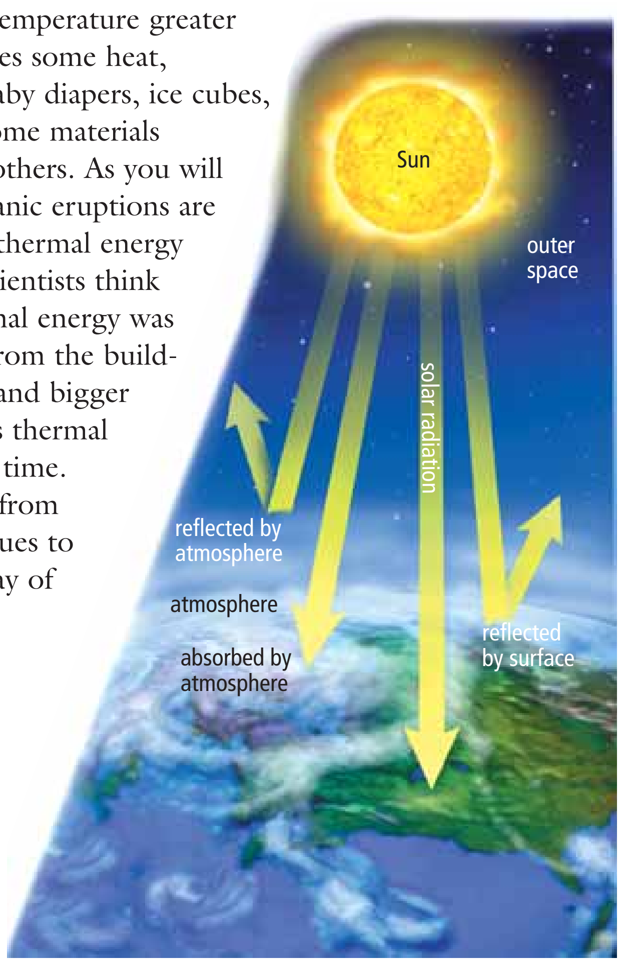


Figure 10.11 Solar radiation accounts for much of the thermal energy at Earth's surface.

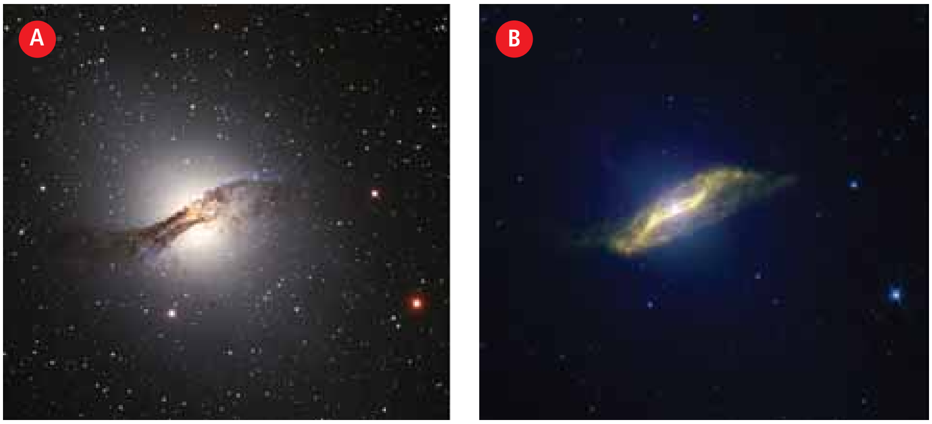


Figure 10.12 Like the Sun, this newly forming star is a source of both visible light (A) and infrared radiation (B).

Materials absorb, reflect, or transmit radiation. Heat is transferred when a substance absorbs radiation, causing it to increase in temperature, melt, or evaporate. Section 10.2 explores what happens to solar radiation and how the transfer of thermal energy affects the atmosphere.

Connection

Chapter 7 has more information on radiation.

Explore More

Find out more about scientists' hypotheses to explain how thermal energy became trapped in the newly formed Earth. Start your search at **www.bcscience10.ca**.

10-1B Conduction in Action

Conduct an INVESTIGATION

Inquiry Focus

Skill Check

- Observing
- Measuring
- Graphing
- Evaluating information

Safety

- Be careful not to burn yourself on the hot plate.
- Follow your teacher's safety instructions.

Materials

- four 8 cm conduction bars (steel, brass, copper, aluminum)
- felt pen
- ruler
- wax strips or candles
- matches
- hot plate
- brick or block of wood
- stopwatch
- graph paper
- coloured pens or pencil crayons

In this investigation, you will work with a group to test the ability of different types of metal to conduct heat.

Question

How can you investigate the rate of conductivity through different metals?

Procedure

1. Copy the following data table into your notebook. Give your table a title.

	Time (s)			
Distance (cm)	**Aluminum**	**Brass**	**Copper**	**Steel**
0.0	0.0	0.0	0.0	0.0
2.0				
8.0				

2. Label each metal bar with the felt pen: A (aluminum), B (brass), C (copper), and S (steel).
3. Use the ruler and felt pen to make marks along each bar at 1 cm intervals.
4. If you are using wax strips: Starting at the 2 cm mark, place a wax strip at every mark along each metal bar. If you are using candles: Light a candle. Starting at the 2 cm mark, carefully drop a spot of wax at every mark along each metal bar.
5. Place each of the metal bars on the hot plate, as shown in the above figure. Support the bars with your hand so that only the first 2 cm of each bar is on the hot plate.
6. To keep the metal bars from falling when you take away your hand, place a brick or block of wood on the ends of the bars that are touching the hot plate.
7. Turn on the hot plate, and start the stopwatch.
8. Observe how long it takes for the wax to melt at each position along each metal bar. Record the times in your data table. So that you do not miss any of the readings, each group member should be responsible for observing a particular metal bar.
9. Once the materials have cooled and are safe to touch, clean up and put away the equipment you have used.
10. Graph your results in a time versus distance graph. Using a different colour or symbol for each metal, draw four best-fit lines.

Analyze

1. How could you tell that heat was being conducted along the metal bars?
2. (a) Did all of the metals conduct heat equally well?
   (b) If not, rate the metals in order from best to worst thermal conductor.

Conclude and Apply

1. Use the kinetic molecular theory to explain how thermal energy was transferred along the metal bars.
2. Which of the metals would you use to stir a hot mixture? Explain your answer.

10-1C Coloured Convection Currents

Conduct an INVESTIGATION

Inquiry Focus

Skill Check

- Observing
- Measuring
- Communicating
- Modelling

Safety

- Use caution when handling the hot water.
- Be careful using glass containers and thermometers.
- Follow your teacher's safety instructions.

Materials

- glass baking dish (approximately 4 cm × 12 cm × 30 cm)
- water (hot and cold)
- 2 ring stands
- 3 thermometer clamps
- 3 thermometers
- 250 mL beaker
- beaker tongs
- medicine dropper
- food colouring
- stopwatch
- 4 Styrofoam® or plastic cups to raise the baking dish

Particle movement affects the density of matter. In this investigation, you will model the flow of convection currents with liquid of varying temperatures and densities.

Question

How is thermal energy transferred in a fluid?

Procedure

1. Copy the following data table into your notebook. Allow enough rows to record the temperature every 10 s. Give your table a title.

	Temperature (°C)		
Times (s)	Thermometer 1	Thermometer 2	Thermometer 3
0			
10			
180			

2. Set up the apparatus as shown in the diagram. Fill the baking dish about $\frac{3}{4}$ full of cold tap water. Use the ring stands and thermometer clamps to submerse the thermometers in the water at three different positions.
3. Fill the beaker with about 225 mL of hot tap water. Use the medicine dropper to add several drops of food colouring to the water in the baking dish. Start the stopwatch. Record the temperature measured by each thermometer at time 0 s. Describe what you see.
4. Use the beaker tongs to carefully place the beaker of hot water under the centre of the baking dish. Continue to record the temperatures every 10 s for at least 3 min (or until the coloured water makes one complete circuit). Note the position of the coloured water every 30 s.
5. Clean up and put away the equipment you have used.

Analyze

1. Describe the motion of the coloured water from step 3 on.
2. Draw a cross-sectional sketch showing the path of the coloured water.
3. How did you measure the kinetic energy of the water at different locations?
4. How did the thermometer readings change with respect to the movement of the coloured water?

Conclude and Apply

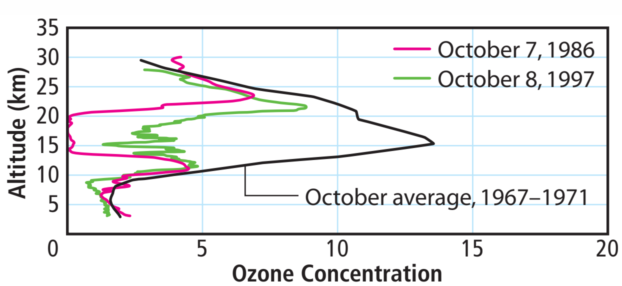
1. Compare the densities of cold and hot water.
2. Use the kinetic molecular theory to explain the movement of the coloured water.
3. (a) Like liquids, gases are fluids. Compare the densities of cold and hot air.
   (b) How might variations in the density of air lead to convection currents in the atmosphere?
4. What visible evidence could you look for that would indicate that there were convection currents in air?

Science Math connect

Graphing Earth's Ozone Profile

Our atmosphere contains a naturally occurring form of oxygen called ozone (O_3). The ozone layer does for the planet what sunscreen does for us when we expose our skin to sunlight. It blocks much of the harmful ultraviolet radiation from the Sun.

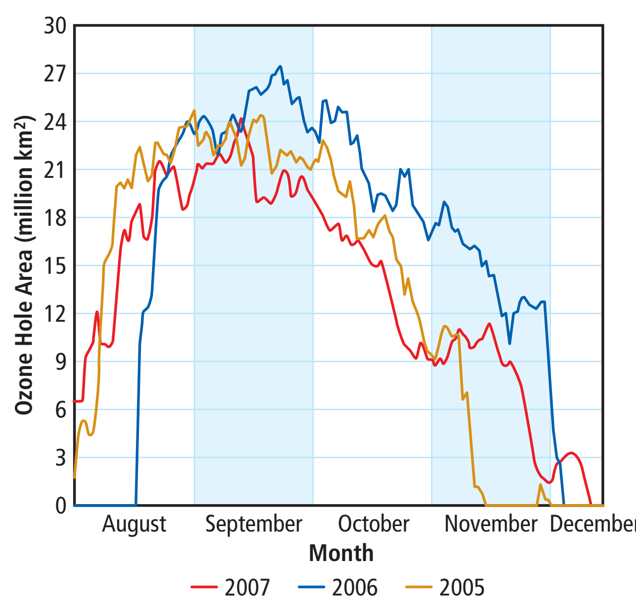
In the 1960s, scientists were surprised to observe a hole in the ozone layer over Antarctica. To get accurate data on the ozone layer, weather balloons were regularly launched from the ground in Antarctica. As they rose many kilometres into the air, instruments on the weather balloons measured ozone concentrations. Graph A compares ozone concentrations at different altitudes in October 1986 and 11 y later. The figure also shows the average ozone concentration at different altitudes for October between 1967 and 1971.



Graph A Ozone concentration at different altitudes

Graph A provides three kinds of information. First, altitude is plotted on the vertical (y) axis. The bottom of the graph shows ozone concentrations near the ground. As you follow each line up the graph, it shows the concentrations at higher altitudes. Second, the horizontal (x) axis shows ozone concentration. Notice how at 15 km the black line goes farthest of all to the right. This shows that, before the ozone hole opened up, the concentration of ozone at this altitude was relatively high. In comparison, the green and red lines show a drop to nearly zero concentration of ozone at 15 km. This comparison between measurements from different years is the third piece of information that the graph provides.

Scientists realized that certain chemicals used in cooling appliances and aerosol spray cans were destroying the ozone layer. Government regulations were eventually put in place to stop the use of ozone-depleting chemicals. Graph B shows the area of the ozone hole at different times between 2005 and 2007. To read the graph, follow the blue line until it reaches its highest point, which is in late September. At this point, the ozone hole was at its largest for the period between 2005 and 2007. The red line shows that in 2007 the ozone hole was smaller than in 2006 (blue) and 2005 (orange). The downward trend is good news. It suggests that efforts to stop ozone depletion are working.



Graph B Area of ozone hole over Antarctica

Questions

1. At what altitude was ozone at its highest concentration on October 7, 1986?
2. (a) Which range of altitudes was most severely affected by ozone depletion?

   (b) Why is ozone depletion in this range a problem?
3. Estimate when in 2007 the size of the ozone hole reached 24 million km^2.

Check Your Understanding

Checking Concepts

1. Copy and complete the following question in your notebook. Match the term in column A with the correct description in column B.

A		B
(i) heat	____	(a) the total energy of all the particles in a solid, liquid, or gas
(ii) temperature	____	(b) amount of thermal energy transferred between different areas or objects
(iii) thermal energy	____	(c) the energy of a particle or object due to its motion
(iv) kinetic energy	____	(d) a measure of the average kinetic energy of all the particles in a sample of matter

2. Name the correct temperature scale (Fahrenheit, Celsius, or Kelvin) for each of the following values. The values are the temperatures at absolute zero (the temperature at which all particle motion stops).
   (a) 0°
   (b) −273°
   (c) −460°
3. Create a table to compare and contrast the transfer of heat by conduction and convection. Use the following headings in your table.
   - States of Matter Involved
   - Examples of Materials Involved
   - How Particles Interact
   - What Is Transferred?
4. If you leave lights on in a closed room, the air inside the room will start to feel hot. What type of energy transfer is involved in this situation? Explain.
5. What part of the electromagnetic spectrum makes the sidewalk feel warm on a sunny day?

Understanding Key Ideas

6. Explain how thermal energy is transferred from a hot stove element to soup in a pot. Refer to the motion of atoms and molecules in your response.
7. Can conduction occur between a hot beaker and your hand if you do not touch the beaker? Explain.
8. Suppose you pour some hot water into a sink full of cold dishwater. What could you do to make the water in the sink heat up more evenly? Use the kinetic molecular theory to explain your answer.
9. Why does a house with a snow-covered roof stay warmer inside than it would if there were no snow on the roof?
10. Name the type of heat transfer indicated by each letter in the following photograph.

Pause and Reflect

On a hot day, you might have heard someone say that it is "hot enough to fry an egg on the sidewalk!" Explain how radiation and conduction would make this possible.

10.2 Energy Transfer in the Atmosphere

Life on Earth depends on the atmosphere. Solar radiation transfers heat to Earth. Conduction and infrared radiation from Earth's surface help to heat the atmosphere. Atmospheric pressure, air temperature, and humidity vary throughout the atmosphere. Differences in atmospheric conditions affect, and are affected by, convection in the atmosphere. Weather is the condition of the atmosphere at a specific time and place.

Words to Know

atmosphere
Coriolis effect
hurricanes
kilopascals (kPa)
ozone layer
prevailing winds
sea breezes
thunderstorm
tornado

Did You Know?

Your body is surrounded by an insulating layer of air. On a windy day, this layer is blown away, which can make a hot day more pleasant and a cool day dangerously cold. Wind also increases the rate of evaporation of moisture from skin, making the body even cooler. The cooling effect is known as wind chill.

Astronomers have discovered over 240 planets outside our solar system. They believe that many of these planets have **atmospheres**, layers of gases that extend above a planet's surface. They have even detected water in some of these atmospheres. Of all the planets studied, however, only one is known to contain water in three states: solid, liquid, and gas. Only one planet is known to have an atmosphere with the right ingredients, and at the right temperature, to support life as we know it. This planet is Earth.

Earth's atmosphere is not a simple layer of air that surrounds the planet. Rather, the atmosphere is a complex system. In this section, you will learn what makes up the atmosphere, how air in the atmosphere moves, and how the atmosphere transfers thermal energy.

The Origin of Earth's Atmosphere

The composition of rocks that formed on early Earth leads scientists to think that the atmosphere was once very different from the atmosphere we know today. The atmosphere was probably composed of gases released in volcanic eruptions (Figure 10.13). The mixture of gases likely contained more than 50 percent water vapour combined with carbon dioxide gas, sulfur-containing gases, and hydrogen gas—but no oxygen gas.

Most life on Earth cannot survive without oxygen gas. Where did the oxygen gas come from? Scientists have done computer modelling that suggests that oxygen gas first appeared when sunlight broke apart water molecules in the upper atmosphere. The next stage of oxygen production

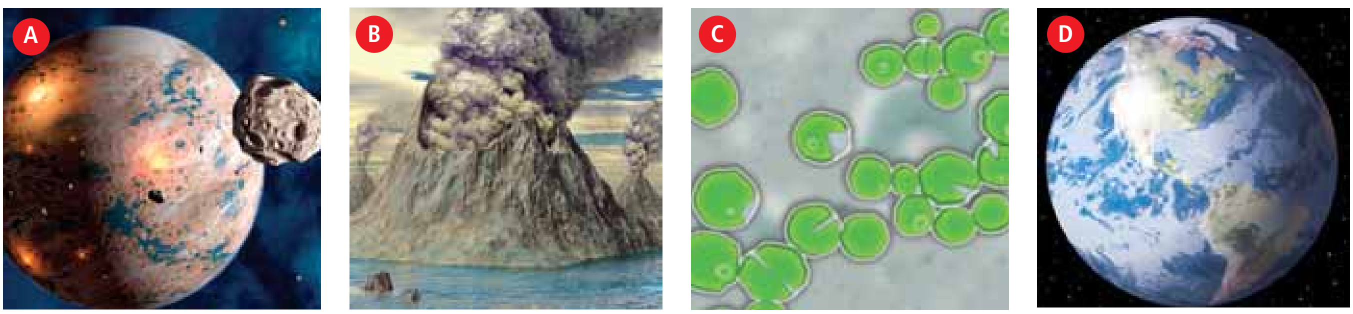


Figure 10.13 The formation of Earth's atmosphere. Earth cools (A). Volcanic eruptions release steam, which condenses and forms the oceans (B). Photosynthetic micro-organisms produce oxygen gas (C). Earth is now blanketed by a nitrogen- and oxygen-rich atmosphere (D).

came much later, with the appearance of photosynthetic micro-organisms. Like plants, these single-celled organisms used sunlight and carbon dioxide to make sugar. At the same time, the process of photosynthesis produced large amounts of oxygen gas. Eventually, the balance of carbon dioxide to oxygen in the atmosphere stabilized. Biological and geological processes have maintained this balance until recent times.

What we call "air" is a combination of gases in the lower atmosphere, near Earth's surface. The two main gases in the lower atmosphere are nitrogen and oxygen, which together make up 99 percent of dry air (air that does not contain water vapour). Most of the remaining 1 percent is argon gas and carbon dioxide gas (Figure 10.14). The atmosphere also contains very small amounts of the gases hydrogen, helium, methane, and ozone, among others.

The composition of the atmosphere remains fairly constant to a height of about 80 km above sea level. However, if you were to climb a tall mountain, you might notice that the air becomes thinner (less dense) the higher you climb, making it harder to breathe in enough oxygen. Above 80 km the particles in air are spread very far apart.

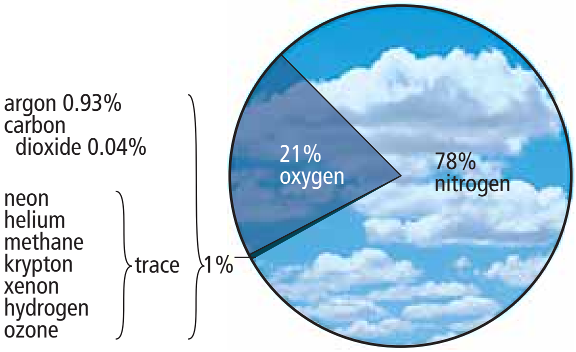


Figure 10.14 The composition of Earth's atmosphere. Water vapour is not included because the amount of water vapour varies throughout the atmosphere.

10-2A Temperature in Earth's Atmosphere — Find Out ACTIVITY

Earth's atmosphere is composed of five thick layers that blend into one another, much like layers of pudding and cake in a dessert. Temperatures at different altitudes are extremely variable. In this activity, you will plot the average temperature of the atmosphere at increasing altitudes.

Materials

- ruler
- 21.5 × 28 cm sheet of graph paper

What to Do

1. On the back of your graph paper, make a rough sketch of how you think a graph of temperature at increasing altitudes in the atmosphere would look. You do not need to put number scales on the *x*- or *y*-axes.
2. Prepare your graph paper. Label the *x*-axis as "Temperature (°C)" and the *y*-axis as "Altitude (km)." The range of values on the *x*-axis should extend from −95°C to +25°C. The range of values for the *y*-axis should extend from 0 km to 140 km.
3. Plot the points from the following data table on your graph paper.
4. Connect the points in order using a best-fit smooth curve.

Temperature (°C)	Altitude (km)
20	0
−15	5
−58	10
−58	15
−58	20
−35	30
−15	40
0	50
−20	60

Temperature (°C)	Altitude (km)
−55	70
−82	80
−90	85
−90	90
−85	95
−70	100
−40	110
−12	120
16	130

What Did You Find Out?

1. How did your plotted graph differ from your predicted graph? Explain.
2. Why is the plotted graph not a straight line?
3. Based on your graph, predict the temperature of the atmosphere at a height of: (a) 135 km above sea level; (b) 140 km above sea level. Explain your answers.
4. Suggest two factors that might account for the difference in temperature in the atmosphere between:
   (a) 2 km and 10 km above sea level
   (b) 10 km and 120 km above sea level

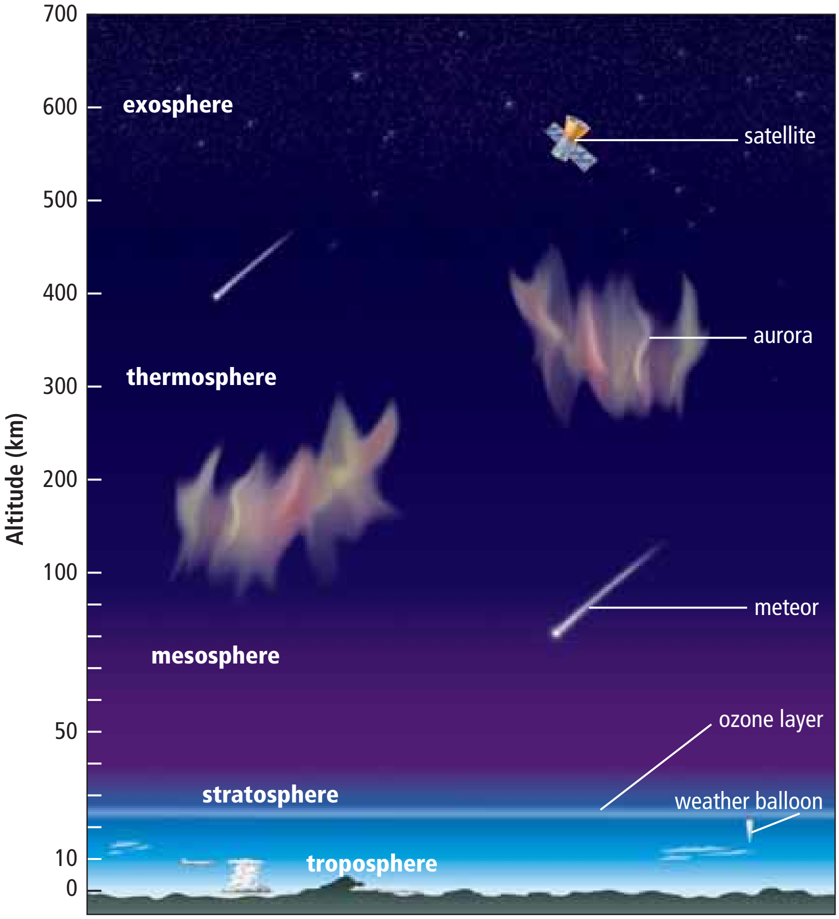


Figure 10.15 The five layers of Earth's atmosphere

The Layers of the Atmosphere

Earth's atmosphere is made up of five layers, which differ in average altitude, chemical composition, average temperature, and density. The altitudes given in Figure 10.15 are averages, since the exact altitude of any layer over a particular point on Earth's surface will differ somewhat depending on the time of day. The five layers of Earth's atmosphere are:

- the troposphere
- the stratosphere
- the mesosphere
- the thermosphere
- the exosphere

The troposphere

The **troposphere** is the lowest layer of Earth's atmosphere. On average, the troposphere is about 10 km thick, but it ranges from 8 km thick at the poles to 16 km thick at the equator. Because the troposphere is the bottom layer, the mass of the upper atmosphere compresses its gas molecules, making it the densest of all the layers.

Almost all water vapour in the atmosphere is found in the troposphere, which is why the weather takes place in this layer. Solar radiation and heat emitted from Earth's surface affect the air in the troposphere, causing the air to move around continuously. The troposphere also contains most of the particulate matter (dust) that exists in the atmosphere. This particulate matter can include pollutants, pollen grains, or ash from volcanic eruptions.

The temperature in the troposphere drops by about 6.5°C for every 1 km increase in altitude. The average temperature at the bottom of the troposphere is 15°C. At the top of the troposphere, the average temperature is about −55°C.

The stratosphere

At the top of the troposphere is a transition zone, called the tropopause, which marks the boundary between the troposphere and the next layer in the atmosphere—the **stratosphere**. Transition zones are not absolute boundaries, as their altitudes are affected by changes in patterns of air movement, temperature, and air density.

Compared to the troposphere, the stratosphere has dry air with few clouds. The lower portion has a fairly constant temperature of about −55°C, while the upper stratosphere gets slightly warmer with increasing height. At about 50 km, the top of the stratosphere, temperatures can reach 0°C. The winds in the stratosphere are strong and steady. Passenger airplanes often fly close to the bottom of the stratosphere—about 10 km above sea level—to avoid the motion caused by convection currents in the troposphere.

The stratosphere acts as a barrier that helps contain moisture in the troposphere and also blocks out damaging radiation from the Sun. An important part of the stratosphere is the ozone layer. Ozone is a molecule composed of three oxygen atoms. Although there are at most 12 ozone molecules for every million other molecules in the **ozone layer**, the layer absorbs much of the ultraviolet radiation from the Sun. As a result of absorbing this radiation, the stratosphere heats up.

The upper atmosphere

Above the stratosphere is the **mesosphere**, which extends from about 50 to 80 km above sea level. Temperatures in the mesosphere can reach as low as −100°C. Every day, millions of small pieces of dust and meteors crash through the mesosphere. As they collide with particles in the mesosphere, thermal energy is released and the space debris burns up. The burning pieces of matter are the shooting stars you can see in the night sky (Figure 10.16A).

The fourth layer of Earth's atmosphere is the **thermosphere**, which extends from about 80 km to 500 km above sea level. At the top of the thermosphere, where the solar radiation is the strongest, temperatures can reach 1500°C to 3000°C. When charged particles in Earth's magnetic field collide with particles in the thermosphere, a bright glow can be seen. In the northern hemisphere, this glow is referred to as the northern lights, or aurora borealis (Figure 10.16B).

The fifth layer of Earth's atmosphere is the **exosphere**. The top of the exosphere is not well defined and merges with outer space at an altitude of about 700 km.

Figure 10.16 Most meteorites occur in the mesosphere (A). The aurora borealis results from collisions of particles in the thermosphere (B).

Did You Know?

If all the molecules of the ozone layer were compressed together, they would form a layer only 3 mm thick—the thickness of two pennies stacked together. Yet the ozone layer is extremely important to life on Earth. Without this layer, Earth's surface would be bombarded with ultraviolet radiation, which damages cells. In particular, DNA, the genetic material of living organisms, readily absorbs ultraviolet radiation type B (UVB). UVB can cause changes in DNA that can kill cells or cause cancer.

Word Connect

The word "troposphere" comes from the ancient Greek word *tropos*, which means to turn or mix. "Thermosphere" has its roots in the Greek word *thermos*, which means hot.

Reading Check

1. How did Earth's atmosphere form?
2. What two elements make up 99 percent of Earth's atmosphere?
3. What features do scientists use to characterize each layer of the atmosphere?
4. What are the five layers of Earth's atmosphere?
5. Which is the lowest level of the atmosphere?

Figure 10.17 Solar radiation reaches British Columbia when it is day in North America.

Radiation and Conduction in the Atmosphere

Only a tiny portion of solar radiation reaches Earth. Even so, almost all energy on Earth comes from the Sun. Waves of solar radiation transfer their energy when they are absorbed by matter, whether solid, liquid, or gas. Much of the solar energy is converted to thermal energy as particles move faster and transfer kinetic energy to each other. Areas that receive the most solar radiation gain the most thermal energy (Figure 10.17). The amount of solar radiation that reaches a certain area is called **insolation**. Insolation is measured in watts per square metre (W/m^2). For example, water in the Pacific Ocean near the equator receives more insolation and is warmer than water in the Arctic Ocean.

Particles of matter in the atmosphere interact with solar radiation, reducing insolation at Earth's surface. A region's location on Earth also affects how much insolation it receives. As a result, locations at higher latitudes receive less insolation (Figure 10.18). **Angle of incidence** is the angle between a ray reaching a surface and a line perpendicular to that surface. At the equator, the angle of incidence of the Sun's rays is 0°. In comparison, at higher latitudes the angle of incidence of the Sun's rays is much greater. In other words, the same amount of incoming solar radiation is spread over a larger area. You will learn more about the effect of the angle of incidence of the Sun's rays in Chapter 11.

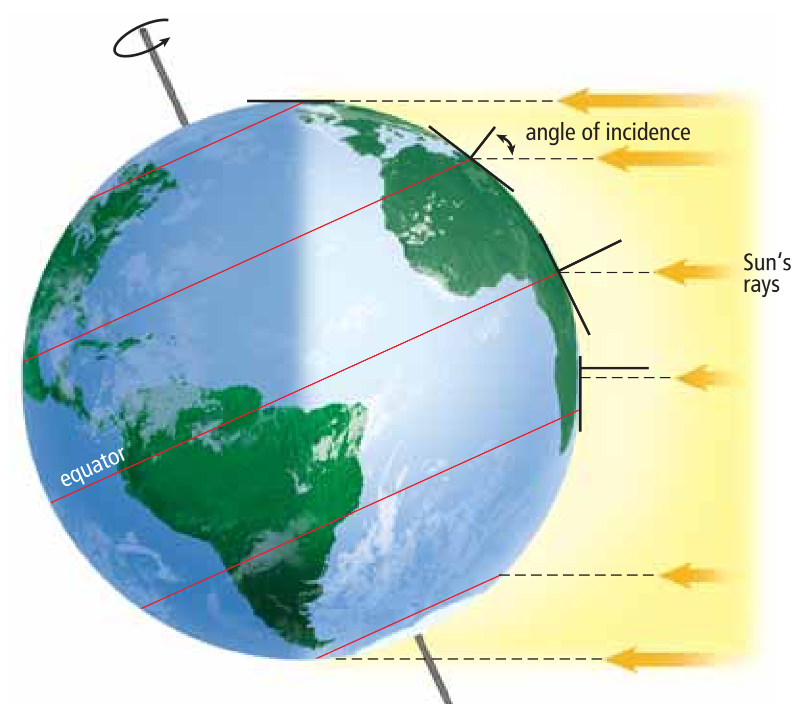


Figure 10.18 The angle of incidence of the Sun's rays is greater towards the poles than towards the equator. Therefore, solar radiation is more spread out at the poles.

How does insolation at Earth's surface relate to radiation in the atmosphere? It might surprise you to know that very little solar radiation heats the atmosphere directly. Solar radiation comes in short wavelengths, some of which pass through the atmosphere to Earth's surface, where they are absorbed. Earth's surface reradiates some of this energy as longer, infrared waves (Figure 10.19). The atmosphere absorbs the infrared radiation. Convection transfers the thermal energy throughout the atmosphere. (You will return to convection in the atmosphere later in section 10.2.)

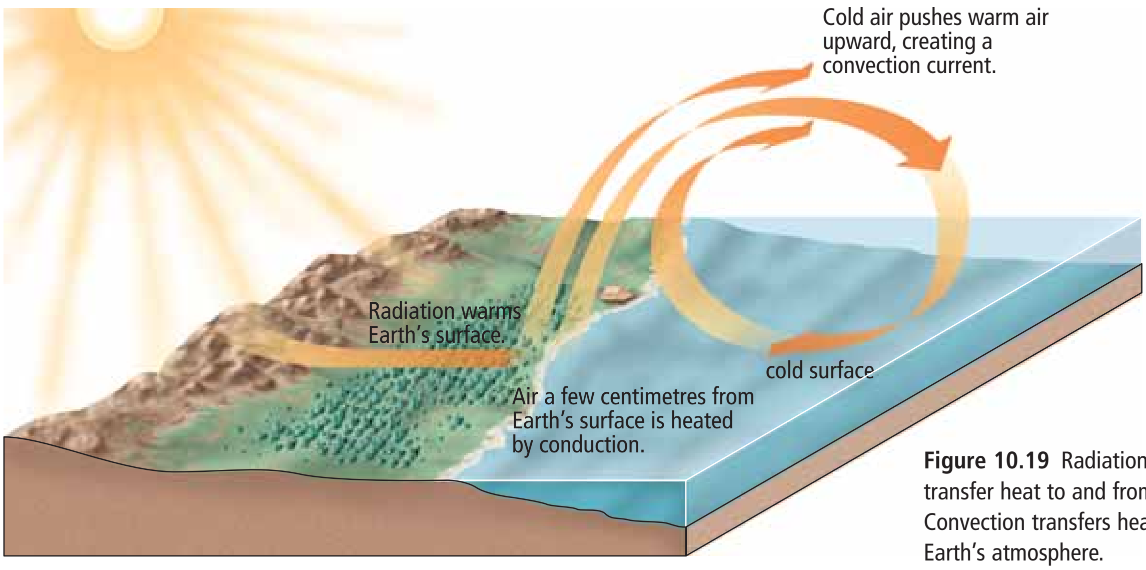


Figure 10.19 Radiation and conduction transfer heat to and from Earth's surface. Convection transfers heat throughout Earth's atmosphere.

Conduction transfers heat in the lowest part of the troposphere, near Earth's surface. The ground transfers heat to particles in the air directly above it. The particles in the air heated directly by Earth's surface collide with particles in the lowest level of the atmosphere, and the temperature of the air increases.

The radiation budget

An average of 342 W/m^2 of solar radiation reaches the top of Earth's atmosphere. If all of this energy were stored in Earth's atmosphere, the planet would heat up, making it uninhabitable. However, Earth is said to have a **radiation budget**, which keeps incoming and outgoing energy in balance. Imagine you have a savings account of $100. If you budget your money so that you take out just as much as you deposit each month, your account will be balanced at $100. Similarly, the radiation budget accounts for incoming and outgoing radiation (Figure 10.20 on the next page).

The incoming solar radiation is reflected by clouds (15 percent) and dust in the atmosphere (7 percent). Another 20 percent is absorbed by clouds and the atmosphere. The remaining 58 percent of incoming solar radiation reaches Earth's surface, but only some is absorbed by the land and water. About 9 percent of incoming solar radiation is reflected back to outer space by Earth's surface.

Ultimately, the energy absorbed by Earth's surface and atmosphere will be radiated back into space. A number of sources emit the absorbed energy as longer wave radiation: evaporation and sublimation of water (23 percent), conduction and convection (7 percent), and infrared radiation from Earth's surface (19 percent). Clouds and atmospheric gases temporarily trap much of the radiation from Earth's surface and then release it in all directions, including back into space.

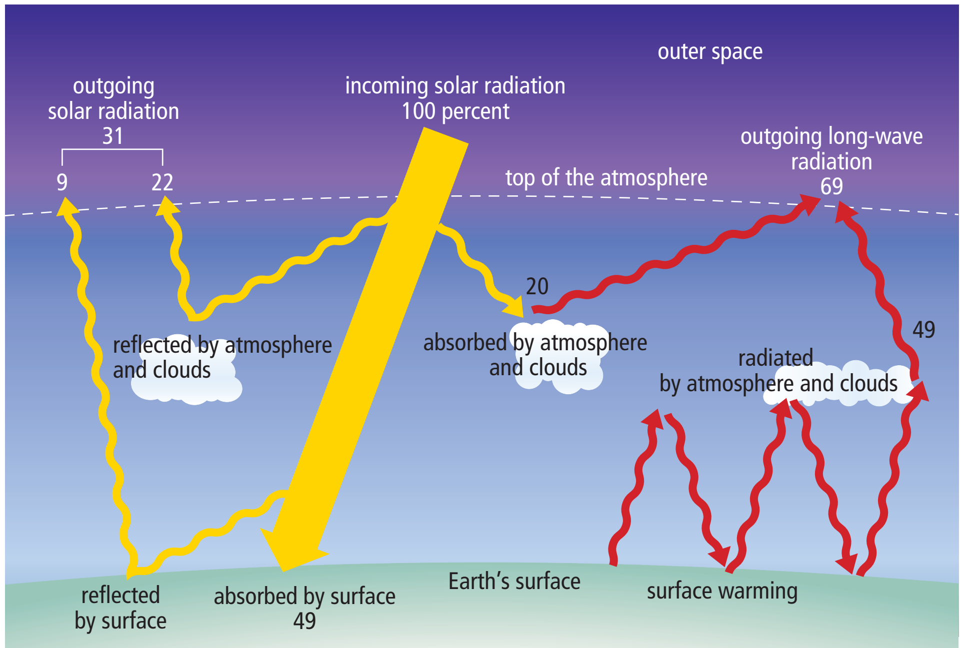


Figure 10.20 The radiation budget is achieved partly because Earth does not absorb 100 percent of the radiation it receives. Earth's surface and atmosphere reflect some of the incoming solar radiation. Earth's surface also emits some of the radiation that it absorbs. The percentages shown here are estimates.

Albedo

The physical characteristics of a substance affect how much radiation it will absorb or reflect. Dark areas of continents, for example, will absorb more radiation than areas covered in ice and snow.

Albedo describes the amount of radiation reflected by a surface. Albedo is an important quantity when discussing the transfer of thermal energy in the atmosphere. The amount of reflection from land depends greatly on the ground cover. Snow-covered areas and deserts have high albedos; many forests and soils have low albedos. If Earth were a giant snowball, about 85 percent of the solar radiation reaching the planet's surface would be reflected back into space. If Earth were entirely covered in water, most of the incoming solar radiation would be absorbed and the planet would be much warmer than it is now.

Human activities, from deforestation to generating air pollution, can change the albedo of Earth's surface. You will explore the relationship between climate and albedo in Chapter 11.

Reading Check

1. How does the Sun transfer heat to Earth?
2. What is the radiation budget?
3. Describe three things that can happen to the solar radiation that reaches Earth's atmosphere.
4. How does conduction transfer heat from Earth's surface to the atmosphere?
5. What does it mean to say that a ground cover has a "low albedo"?

Did You Know?

If all the solar energy that is absorbed by Earth and its atmosphere in 1 s could be converted to electricity, that energy could supply the needs of British Columbia for thousands of years.

What Is Weather?

Weather is the condition of the atmosphere in a specific place and at a specific time (Figure 10.21). Weather describes more than clouds, rain, lightning, and storms. Weather describes all aspects of the atmosphere, including temperature, atmospheric pressure, amount of moisture in the air, and wind speed and direction.

Weather is closely connected to heat transfer in the atmosphere. Convection moves air and thermal energy throughout the troposphere, causing various kinds of weather experienced at Earth's surface. As the following pages explain, atmospheric pressure plays a key role in the convection of air in the atmosphere.

Suggested Activity

Conduct an Investigation 10-2B on page 455

Figure 10.21 Weather—in this case, bad weather—refers to various conditions in the atmosphere at a specific place and a specific time.

Figure 10.22 Atmospheric pressure exerts force on you from all directions.

Atmospheric Pressure

If you have ever dived deep under water, you probably noticed extra pressure all over your body and in your ears in particular. What you were feeling was the pressure of the water above you. Likewise, while you are sitting in a classroom, Earth's atmosphere exerts pressure on you.

In previous studies, you may have learned that force is the push or pull that acts on an object. For example, a wall exerts a force on your foot when you stub your toe. The force of gravity pulls your books to the ground when you drop them. **Pressure** is the amount of force per unit area.

Molecules in the air move continuously in all directions. As they collide with a nearby surface—such as you—they exert force on it. Air pressure, or **atmospheric pressure**, is the pressure exerted by the mass of air above any point on Earth's surface (Figure 10.22).

Measuring atmospheric pressure

We can measure atmospheric pressure using an instrument called a **barometer**. One of the first barometers was developed in 1643 by Italian physicist Evangelista Torricelli (1608–1647). Torricelli placed a narrow glass tube, filled with liquid mercury and with one end closed, upside down in a saucer of mercury (Figure 10.23A). The mercury inside the inverted tube sank slightly. At sea level, atmospheric pressure on the mercury in the saucer prevented the mercury inside the tube from falling below about 76 cm. Torricelli connected the height of the mercury with the atmospheric pressure. He also noticed something peculiar—the level of the mercury in the tube went up or down with changes in the weather.

Today, the aneroid barometer is the most common type used in homes (Figure 10.23B). The barometer contains a capsule made of flexible metal. Slight changes in atmospheric pressure make the capsule expand or contract.

Suggested Activities

Find Out Activity 10-2C on page 456
Conduct an Investigation 10-2D on page 457

Figure 10.23 A copy of Toricelli's experimental barometer (A). An aneroid barometer (B)

The SI unit for atmospheric pressure is the pascal (Pa). Pascals are used to measure the vertical force per unit area. One pascal has a force of one newton per square metre, or 1 N/m^2. This is a very small amount, so most measurements are given in **kilopascals (kPa)**. There are 1000 Pa per kPa. You might hear the term kilopascal in weather reports or see it used in the guidelines for inflating a bicycle tire.

Word Connect

The pascal (Pa) is named for Blaise Pascal (1623–1662), a French mathematician, physicist, and philosopher. The Pascal computer programming language is also named after him.

Altitude affects atmospheric pressure

At sea level, the atmospheric pressure is about 101.3 kPa, which is equal to 1 kg/cm^2. This means that there is about 1 kg of air pushing down on each square centimetre of your body. Fortunately, the human body can withstand the pressure of Earth's atmosphere! Atmospheric pressure in your body counteracts the atmospheric pressure outside your body. As a result, you will not notice the atmospheric pressure unless it changes.

If you have ever been on a drive up a mountain road or flown in an airplane, you may have experienced "popping" in your ears. As your altitude increases, the density of the air decreases. The gas molecules in the air are spread farther apart and collide with nearby surfaces less often. Therefore, the atmospheric pressure decreases (Figure 10.24). Your ears "pop" to balance the higher atmospheric pressure within your middle ear with the lower external atmospheric pressure.

Temperature affects atmospheric pressure

The kinetic molecular theory explains that as particles are heated they gain kinetic energy and move around more quickly. As a result, warm air is less dense than cold air because the gas molecules in it are farther apart. Warm air is also lighter than cold air.

The movement of air at different temperatures also affects atmospheric pressure. When warm air pushes into an area of cold air near the ground, the atmospheric pressure in that location decreases. When cold air pushes into a region of warm air, the atmospheric pressure in that location increases.

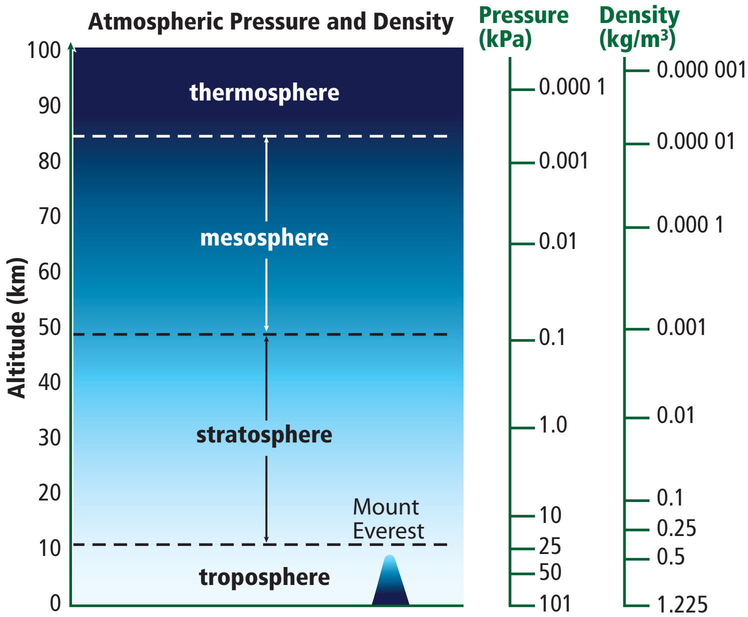


Figure 10.24 Atmospheric pressure and density at increasing altitudes. On average, the atmospheric pressure at the top of the troposphere is only about 10 percent of that at sea level. However, pressure differences vary throughout the troposphere because of the movement of air.

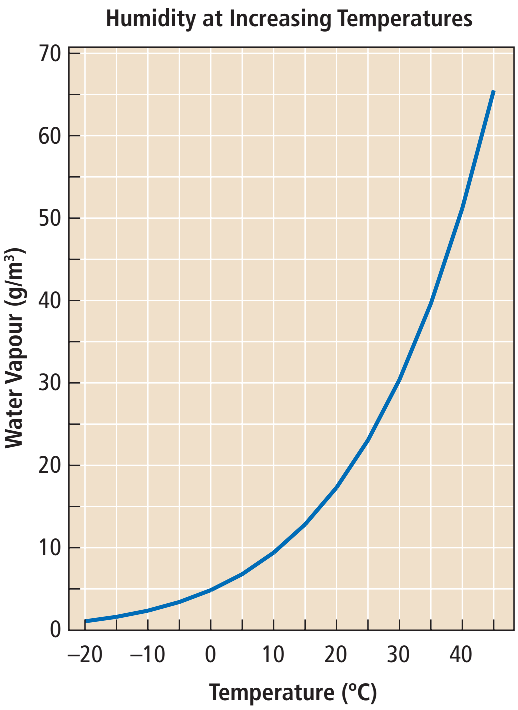


Figure 10.25 The capacity of air to hold water vapour is directly related to the temperature of the air. For every 11°C rise in temperature, air doubles its capacity to hold water vapour. For example, a kilogram of air has a capacity to hold 11 g of water at 15.5°C. At 26.5°C, the same air could hold 22 g of water vapour.

Humidity affects atmospheric pressure

A third cause of atmospheric pressure changes is changing humidity. **Humidity** is a measurement that describes the amount of water vapour in air. The more water vapour in the atmosphere, the lighter the air is. As water vapour is added to a region of the atmosphere, it displaces (pushes out) an equal volume of dry air. Oxygen gas and nitrogen gas make up about 99 percent of dry air. They are heavier than water vapour, and so if water vapour displaces some of the oxygen gas and nitrogen gas from a certain volume of air, the air will become lighter. Therefore, humid, or "wet," air exerts less atmospheric pressure than dry air.

Meteorologists are scientists who study weather. They use atmospheric pressure readings to predict changes in the weather. A decrease in atmospheric pressure suggests that warm, humid air is approaching and that the temperature will increase. An increase in atmospheric pressure suggests that cool, dry weather is on its way.

Regardless of where you live in British Columbia, you have probably noticed that the air feels more humid on some days than others. This sensation is an indication of the total amount of water vapour in the air, known as **specific humidity**. Specific humidity is expressed as the number of grams of water vapour in 1 kg of air. Another way to express humidity is as the number of grams of water vapour in 1 m^3 of air.

As the temperature of the air increases, its capacity to hold water vapour also increases (Figure 10.25). The air becomes saturated when the specific humidity equals the capacity of air to hold water at a specific temperature, known as the **dew point**. When air is cooled below the dew point, water vapour condenses. If you have a hot shower on a cold morning, you will likely see condensation on your bathroom mirror. This observation suggests that the air is saturated—although hot water is evaporating, an equal amount of water vapour is condensing.

Usually, the amount of water vapour in the air is less than the amount required to saturate the air at a given temperature. Meteorologists refer instead to **relative humidity**, which compares the amount of water vapour in the air with the amount the air *could* hold if it were totally saturated. A relative humidity of 50 percent means the air is about 50 percent saturated. A relative humidity of 100 percent means that the air is completely saturated.

Reading Check

1. Define "weather."
2. What causes atmospheric pressure?
3. What instrument is used to measure atmospheric pressure?
4. List three factors that can decrease atmospheric pressure.

Movement of Air Masses

An **air mass** is a parcel of air with similar temperature and humidity throughout. Conditions in an air mass change to become like the surface below it. An air mass that remains over the Thompson-Okanagan region of British Columbia for much of July, for example, would likely become dry and hot. An air mass that remains off the coast of Vancouver Island for a few weeks would likely gain moisture from the ocean. An air mass can be several thousand kilometres wide and several kilometres thick. Air masses affecting North America mainly come from polar and subtropical regions with high atmospheric pressure as shown in Figure 10.26.

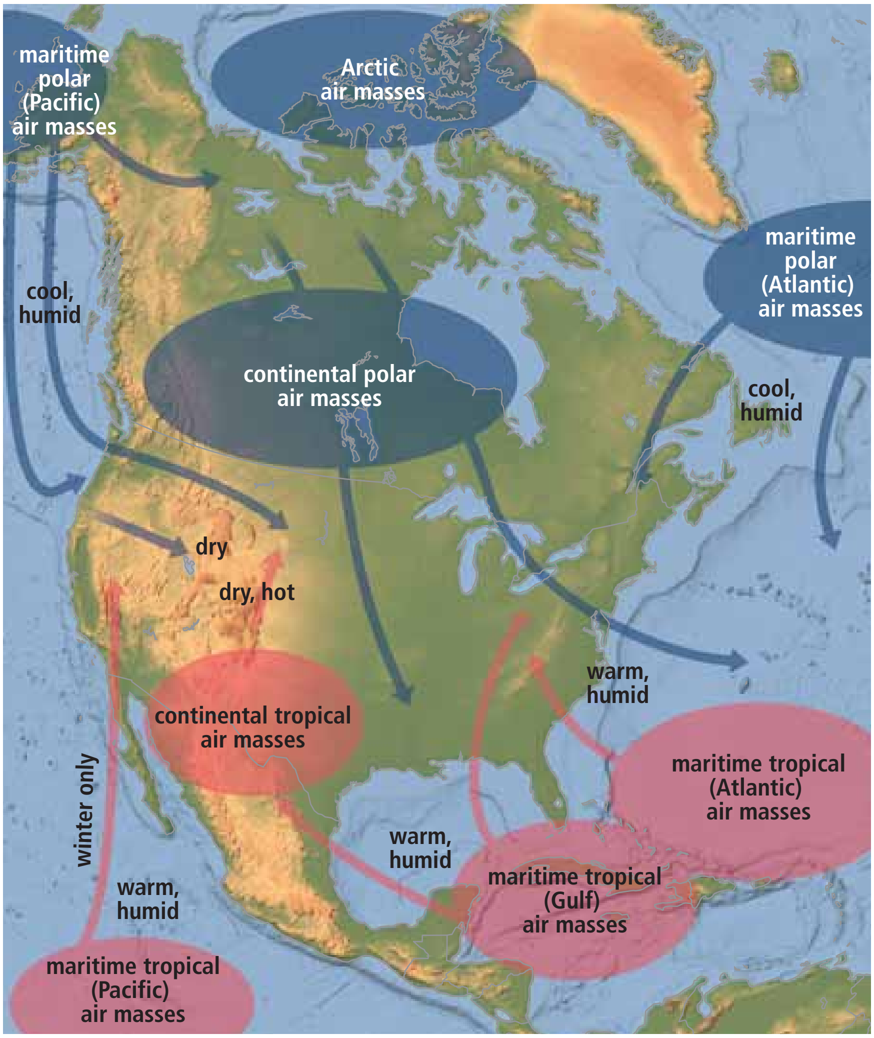


Figure 10.26 Major air masses affecting weather in North America

High pressure systems

When an air mass cools over an ocean or a cold region on land, a high pressure system forms (Figure 10.27). Some high pressure systems are large enough to cover most of North America. As the air mass cools, particles in the air lose kinetic energy and the air becomes denser. The air mass contracts and draws in surrounding air from the upper troposphere. The added weight of the extra air increases atmospheric pressure. The dense, high pressure air moves outward towards areas of lower pressure, creating a wind. **Wind** is the movement of air from an area of higher pressure to an area of lower pressure. Earth's rotation causes the wind to flow clockwise around the high pressure centre. As the high pressure air sinks, it becomes warmer and drier. As a result, high pressure systems often bring clear skies.

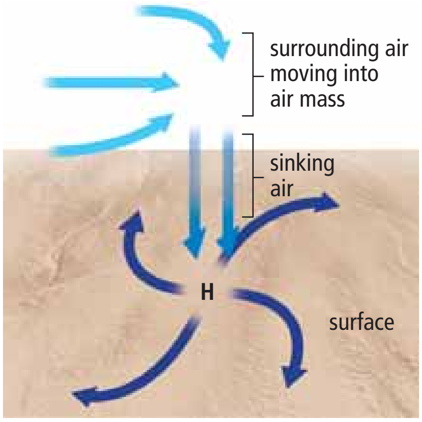


Figure 10.27 In the northern hemisphere, Earth's rotation causes wind to flow clockwise around a high pressure centre (H).

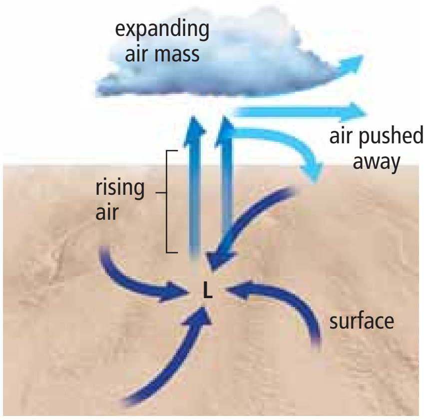


Figure 10.28 In the northern hemisphere, Earth's rotation causes wind to flow counterclockwise around a low pressure centre (L).

Low pressure systems

Air masses that travel over warm land or oceans may develop into low pressure systems (Figure 10.28). When an air mass warms, it expands and rises, making the layer of air thicker. However, as the air rises, it cools. Water vapour in the air may condense, producing clouds or precipitation. This is why low pressure systems often bring wet weather.

Meanwhile, the expanding air mass pushes away air in the upper troposphere. Directly below, at Earth's surface, the atmospheric pressure decreases. The lower pressure area at the surface draws in air from higher pressure areas. As higher pressure air in the atmosphere flows towards a low pressure area, Earth's rotation causes the air flow to curve. As a result, the wind flows counterclockwise around the low pressure centre in the northern hemisphere and clockwise in the southern hemisphere.

Prevailing Winds

Prevailing winds are winds that are typical for a certain region. The prevailing winds of southern British Columbia are moist air masses from the Pacific Ocean that blow inland over the coastal mountains. Cool temperatures and high altitudes cause water vapour in the air to condense, forming rain or snow. As a result, the air carried by these prevailing winds has lost most of its moisture by the time it reaches interior British Columbia (Figure 10.29).

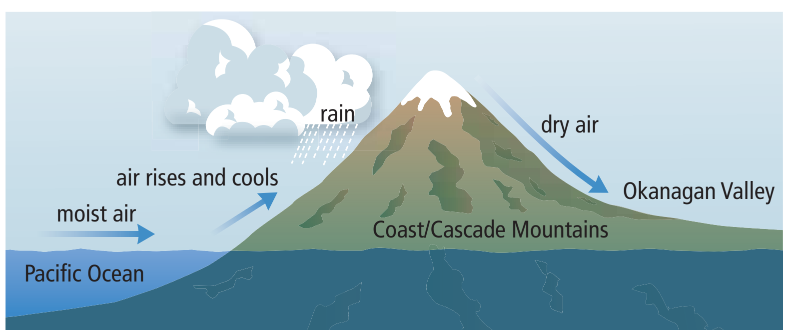


Figure 10.29 Air dries out as winds carry it over the mountains. On the other side, the air descends rapidly, causing strong, dry, warm winds.

Did You Know?

A chinook is a dry winter wind that comes over the Rocky Mountains into the prairies. In Alberta, some First Nations call the chinook "snow eater." The word "chinook" comes from the Chinookan word c'inuk, the name of a village. The Chinook people lived near the mouth of the Columbia River on the Pacific coast.

Prevailing winds are influenced by several factors. Over a short distance, winds follow a fairly straight path from areas of high to low pressure. Over long distances, with massive high and low pressure areas, wind patterns are not so straightforward.

Local winds

Geographic features such as mountains, oceans, and lakes greatly affect the characteristics of winds. It is not surprising that a region like British Columbia, which borders an ocean and contains numerous mountains and lakes, has complex wind systems.

Sea breezes are local winds that are caused by the different rates at which land and water respond to heating and cooling (Figure 10.30). During the day, land heats up faster than a nearby body of water. The land radiates heat, which warms air at the surface. The warm air rises, replaced by cool air drawn in from over the water. The resulting wind, called an **onshore breeze**, usually occurs during the late morning along coastal regions.

During the night, the land cools down faster than the nearby water. The relatively warm air over the water rises and draws in cool air from over the land. This nightly reversal of the sea breeze is called an **offshore breeze**.

Figure 10.30 Sea breezes can be felt as far as 70 km from the coast (A). At night, convection currents reverse and an offshore breeze blows out to sea (B).

The Coriolis effect

Picture what wind patterns might be like if Earth were much smaller and did not spin (Figure 10.31). Warm air at the tropics would rise and travel to the poles, creating convection currents. At the poles, cold, dense air would sink and force its way to the equator. In other words, there would be high pressure systems at the North and South Poles and low pressure systems at the equator.

However, Earth's actual size means that air sinks long before it reaches the poles. As Figure 10.32 shows, air sinks at different latitudes: 30°(N and S), 60°(N and S), and the poles.

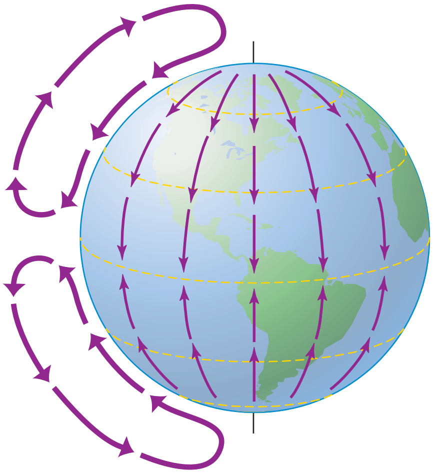


Figure 10.31 If Earth was $\frac{1}{6}$ its actual size and did not rotate, air would rise at the equator and flow directly to the poles, where it would cool and sink.

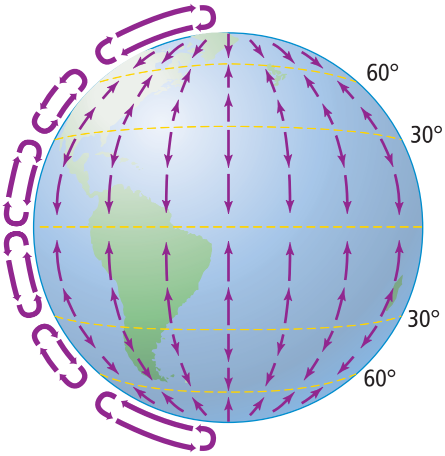


Figure 10.32 Large masses of air circulate between the equator and 30° (N and S). Other convection currents of air circulate between 30° (N and S) and 60° (N and S) and between 60° (N and S) and the poles.

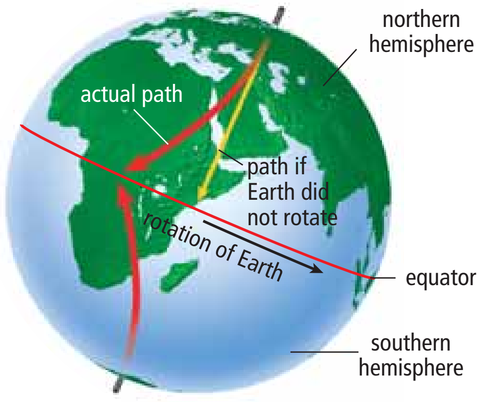


Figure 10.33 The Coriolis effect causes circulating air to curve to the side.

Over long distances, wind is also affected by Earth's rotation. The **Coriolis effect** is a change in the direction of moving air, water, or objects due to Earth's rotation (Figure 10.33). As Earth rotates, any location at the equator travels much faster than a location near either pole. Air rising from the equator travels east quickly in the same direction that Earth rotates. As a result, the Coriolis effect deflects winds to the right in the northern hemisphere, and to the left in the southern hemisphere.

Global wind systems

Wind systems are wide zones of prevailing winds. Figure 10.34 shows Earth's major wind systems, which result from the combination of convection currents and the Coriolis effect.

Earth has three major wind systems, which occur in both hemispheres: the trade winds, the prevailing westerlies, and the polar easterlies (Table 10.1). The trade winds were named by sailors, who historically used these dependable winds, along with the prevailing westerlies, to sail across the oceans in order to trade goods. The prevailing westerlies in the northern hemisphere are responsible for much of the weather in Canada and the United States. As you might expect, the polar easterlies are cold winds from the poles.

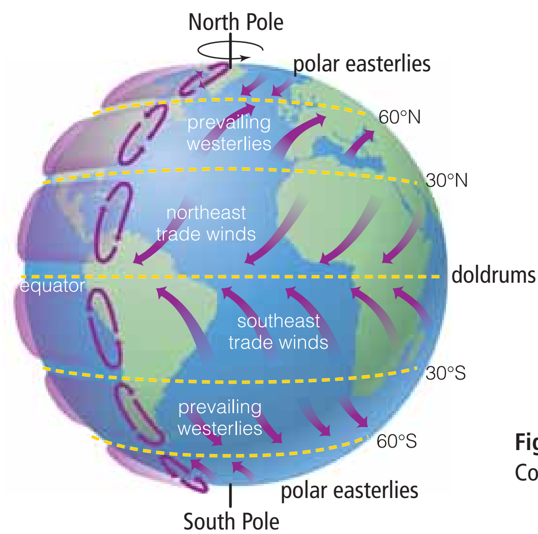


Figure 10.34 Convection currents and the Coriolis effect create Earth's global wind systems.

Word Connect

Between 5° north latitude and 5° south latitude, a belt of low atmospheric pressure spans the equator. Air in this region rises but does not circulate with the trade winds. The result is unpredictable wind behaviour or even no wind at all. Sailors gave the region the depressing name "the doldrums," because being trapped there and unable to sail could be extremely dull. The word "doldrums" means stagnant and listless.

Table 10.1 Global Wind Systems

Wind System	Location	Path
Trade winds	• Between the equator and 30° north latitude • Between the equator and 30° south latitude	• Air at the equator warms, rises, and travels to 30° north or south latitude. • At 30° north or south latitude, the air cools, sinks, and moves west towards the equator.
Prevailing westerlies	• Between 30° and 60° north latitude • Between 30° and 60° south latitude	• Air circulation pattern is opposite to that of the trade winds. • Surface winds blow from west to east and towards the poles.
Polar easterlies	• Between 60° north latitude and the North Pole • Between 60° south latitude and the South Pole	• Air circulation pattern is similar to that of the trade winds. • Surface winds blow from east to west and away from the poles.

Reading Check

1. What causes wind?
2. Name the type of local wind that results from the different rates at which land and water heat up and cool down.
3. What is a prevailing wind?
4. Name the process that causes winds to swerve right in the northern hemisphere and left in the southern hemisphere.
5. List the three major global wind systems and where they occur relative to the equator.

Jet Streams

In the troposphere, Earth's surface and the density of the air produce friction, which slows global winds. In the stratosphere, winds are subject to less friction, and so they can move much faster than winds in the troposphere. A jet stream is a band of fast-moving air in the stratosphere. Jet streams are so strong and fast that airline pilots try to fly with these winds and avoid flying against them.

Several jet streams circle Earth at various latitudes. Figure 10.35 shows two major jet streams over the northern hemisphere. As with other global winds, convection currents in the atmosphere produce the jet streams, and so temperature differences in the atmosphere greatly affect these winds. During cooler times of year, jet streams are faster and occur closer to the equator. The movement of the jet streams also affects the movement of the air beneath them. As a result, changes in the jet streams affect the weather.

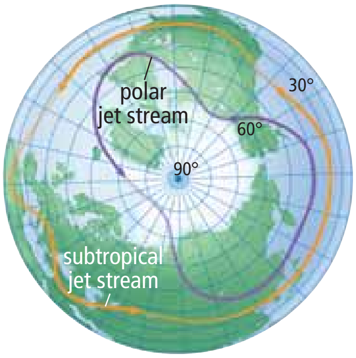


Figure 10.35 The polar jet stream travels eastward at altitudes of about 10 to 12 km.

Fronts

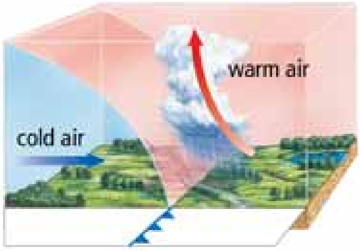
At any given time, several air masses over North America affect the weather in different regions. These air masses interact as they move. Perhaps on a sunny day you have looked to the west and have seen an approaching wide band of clouds. This band of clouds would have indicated the boundary between two air masses, called a **front**. A weather front may be several hundred kilometres wide and thousands of kilometres long.

Each air mass has its own temperature and pressure. These conditions change at the front. An approaching front means a change in the weather, and the extent of the change depends on the degree of difference between conditions in the air masses. Cold, dense air, for example, will slide under warmer air, bringing cooler temperatures and dry weather. Figure 10.36 on the next page shows the characteristics of different types of fronts.

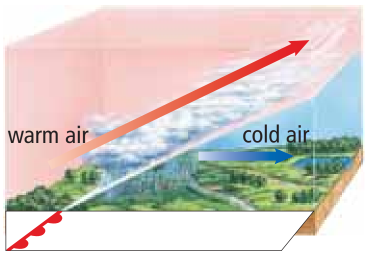
Fronts usually bring precipitation. Warm air at the front is displaced by denser cold air. The warm, moist air rises. As it cools, water vapour in the air condenses, forming clouds. Under the right conditions, the condensed water vapour will fall to Earth's surface as precipitation.

Reading Check

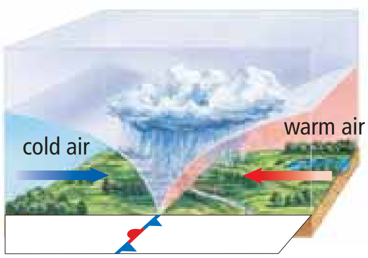
1. Where do jet streams occur?
2. What is a front?
3. What is a stationary front?
4. What kind of weather front results when cold air replaces warm air?



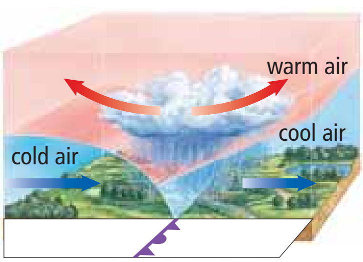
A. A cold front. Cold air advances, displacing warm air.



B. A warm front. Warm air advances, displacing cold air.



C. A stationary front. No air mass is displaced, and the front does not move.



D. An occluded front. A fast-moving cold front overtakes a warm front.

Figure 10.36 Weather fronts and symbols used on weather maps

Extreme Weather

One example of extreme weather is a thunderstorm. **Thunderstorms** are named for the lightning, thunder, strong winds, and hail or rain that they produce. Thunderstorms occur when water vapour in rising warm air condenses, releasing thermal energy. The energy further heats the air, which continues to rise. The condensation produces large thunderheads (cumulonimbus clouds), which precede and accompany thunderstorms. These menacing clouds can reach the top of the troposphere, where the tops spread out and form a typical "anvil" shape (Figure 10.37). Thunderheads can produce extremely heavy rain and even hail. The clouds may also discharge static electricity, known as lightning. Lightning superheats the air to 10 000°C or more, causing it to expand rapidly. The expansion and sudden collapse of the air produces the loud, crashing noise called thunder.

Thunderstorms occur where atmospheric conditions are unstable. Moist air rising rapidly up a mountain or within a cold air mass can produce intense thunderstorms. Sea breezes in the tropics, for example, often result in thunderstorms. Advancing cold fronts and, less often, advancing warm fronts also cause thunderstorms.

Figure 10.37 An approaching thunderhead

Tornadoes

One of the most severe forms of extreme weather is a tornado. A **tornado** is a violent, funnel-shaped column of rotating air that touches the ground. A tornado can form when high-altitude horizontal winds meet large thunderstorms (Figure 10.38). The horizontal winds cause the rapidly rising air in the thunderstorm to rotate, producing a spinning vortex of air called a funnel cloud. In some cases, the funnel cloud touches the ground and becomes a tornado. The tornado follows seemingly random, winding paths, hurling dust and debris in all directions. Surface winds caused by tornadoes have reached 400 km/h.

When tornadoes form over water, waterspouts can occur. Waterspouts are funnel-shaped rotating columns of water. They are sometimes reported off the coast of British Columbia (Figure 10.39).

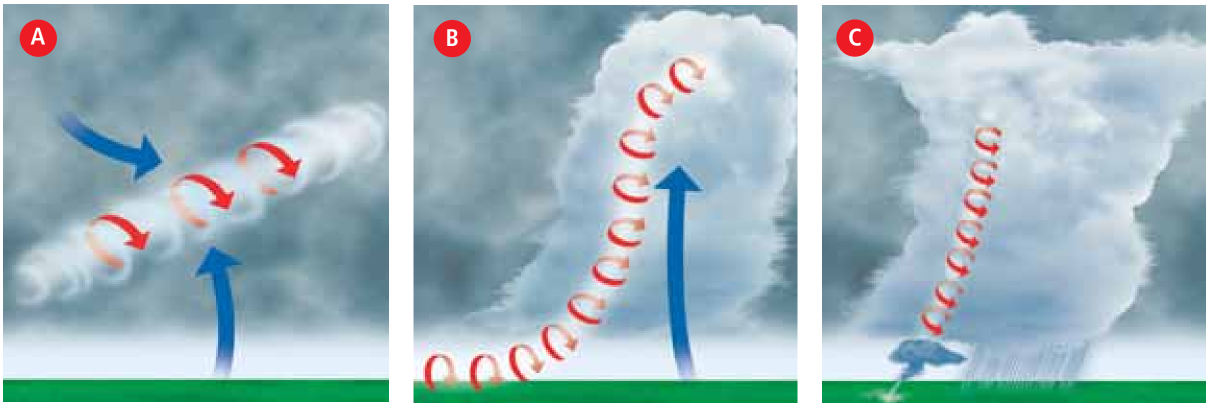


Figure 10.38 When strong horizontal winds hit the rapidly rising air in a thunderhead, funnel clouds can result. Strong winds tilt the funnel cloud (A). The funnel cloud becomes vertical and touches the ground (B). A tornado forms as the funnel cloud travels along the ground (C).

Figure 10.39 Tornadoes occur quite often in the Canadian Prairies during the summer and fall (A). A waterspout (B).

internet connect

Although tornadoes are very unusual in Canada west of the Rocky Mountains, there have been some that have caused loss of life and severe property damage. To find out more about historical tornado damage in Canada, go to **www.bcscience10.ca**.

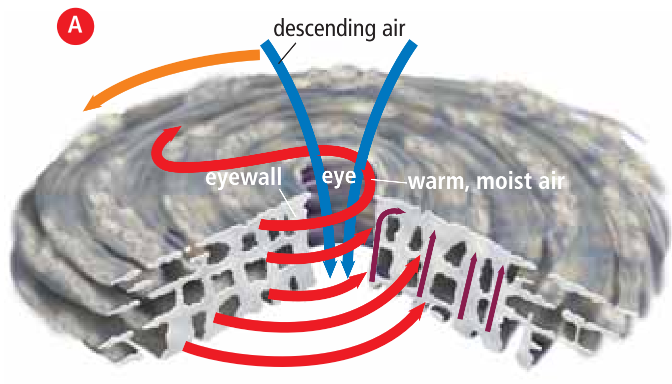


Figure 10.40 Cross-section of a hurricane (A). Satellite image of a hurricane (B)

Tropical cyclones

Some of the world's most violent weather results from the exchange of thermal energy in the tropics. The tropics, the regions closest to the equator, are the ideal location for the formation of intense storms. Together, warm ocean water and winds produce conditions that lift moist air high into the atmosphere (Figure 10.40). The water vapour condenses, producing clouds and rain. The precipitation releases large amounts of thermal energy transferred from the warm ocean water. At the same time, the rising air produces a low pressure area at the ocean's surface. Warm air rushes towards the low pressure area to replace the rising air. The Coriolis effect forces the air to rotate counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. The result is a massive, spinning storm known as a tropical cyclone. It gains speed and momentum as more and more air approaches the low pressure centre. More energy is released with condensation, and the cyclone rotates even faster. Wind speeds may reach 240 km/h.

Tropical cyclones are known as cyclones to people living near the Indian Ocean, typhoons to those near the western Pacific Ocean, and **hurricanes** to those near the Atlantic Ocean. Figure 10.41 shows the location of tropical cyclones around the world. Hurricane season extends from late summer to early fall, the period when the oceans store the greatest amount of thermal energy.

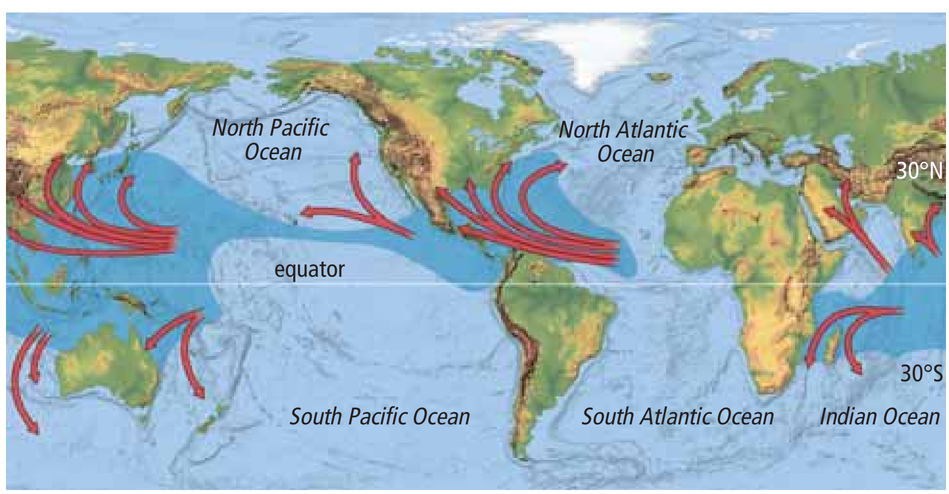


Figure 10.41 Warm waters near the equator create just the right conditions to cause hurricanes to form.

Explore More

The path a tropical cyclone will take is difficult to predict. Find out what meteorologists base their forecasts on by going to **www.bcscience10.ca.**

10-2B Albedo and Colour

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Measuring
- Controlling variables
- Graphing

Safety

- Use caution when handling the lamp as the light bulb will become very hot.

Materials

- three 600 mL beakers
- scoop
- dark coloured soil
- light coloured sand
- cold water
- 100 W light bulb
- lamp or light bulb socket with clamp
- 3 thermometers or temperature probes
- 4 ring stands (optional)
- 3 thermometer clamps (optional)
- clock, watch, or stopwatch
- graph paper
- coloured pens or pencil crayons (optional)

In this investigation, you will use light to heat materials with different albedos.

Question

How does an object's ability to absorb and release radiation relate to its colour?

Procedure

1. Copy the following tables into your notebook. Give each table a title.

Material	Starting Time (min)	Starting Temperature (°C)	Warming Temperature at Each Minute (°C)									
			1	2	3	4	5	6	7	8	9	10
Soil												
Sand												
Water												

Material	Starting Time (min)	Starting Temperature (°C)	Cooling Temperature at Each Minute (°C)									
			11	12	13	14	15	16	17	18	19	20
Soil												

2. Put 100 mL of soil in one of the beakers, 100 mL of sand in a second beaker, and 100 mL of water in the third beaker.
3. Place the beakers on a desk or workbench. Position the lamp about 30 cm above the beakers so that each receives about the same amount of light.
4. Place a thermometer or temperature probe in each beaker. Adjust the position of the thermometers or probes so that they are well covered by the material in the beakers but not in contact with the glass. You can use ring stands and clamps to keep the thermometers in place.
5. In your first data table, record the starting temperature of the material in each beaker.
6. Turn on the lamp and note the time (or start the stopwatch). Record the temperature for each beaker every minute for 10 min.
7. After 10 min, turn off the lamp. In your second data table, record the temperature for each beaker every minute for the next 10 min.
8. Clean up and put away the equipment you have used.
9. Use the data from your tables to graph the heating and cooling of each of the materials. Use a different colour or symbol for each material.

Analyze

1. Which material absorbed the most thermal energy in the first 10 min?
2. Which material lost the most thermal energy in the last 10 min?

Conclude and Apply

1. (a) Of the three materials you used, which would heat up the fastest on a sunny day?
   (b) Which would take the longest to cool down at night?
2. How might the type of surface (e.g., dark rock, water, snow) in an area affect the temperature of the atmosphere above it?

10-2C Effects of Atmospheric Pressure

Find Out ACTIVITY

We live under an immense ocean of air. It is easy to forget that air has mass and exerts pressure. Yet atmospheric pressure is all around you, pushing on you from all directions. In this activity, you will observe the visible effects of invisible atmospheric pressure.

Safety

- Be careful when handling the scissors.

Materials

- wood strapping (about 8 mm thick, at least 60 cm long)
- 1 full sheet of newspaper
- scissors
- 2 balloons
- 60 mL beaker
- 2 elastic bands
- clear adhesive tape
- toothpick
- 1000 mL beaker or large glass jar

What to Do

Part 1 Pressure from Above

1. Place the piece of wood on the edge of a table. Make sure that less than half the length of wood is hanging over the edge.
2. Place the sheet of newspaper over the part of the wood on the table, so that the fold line is directly over the wood. Spread out the paper as flat as possible.
3. Quickly bring your hand down on the unsupported portion of the wood. Note what happens to the wood.

Part 2 Changing Air Pressure

4. Use the scissors to cut open the balloons. Stretch the first balloon across the top of the 60 mL beaker. Use an elastic band to hold the balloon in place so that there is a tight seal around the top of the beaker.
5. Use clear adhesive tape to attach a toothpick to the top of the 60 mL beaker, as shown in the photograph.

6. Carefully place the 60 mL beaker inside the 1000 mL beaker. Stretch the second balloon across the top of the large beaker. Use the second elastic band to form a tight seal around the top of the large beaker.
7. Note where the toothpick is pointing. Gently push down on the balloon at the top of the large beaker. What happened to the toothpick? Record your observations.
8. Carefully pinch the balloon on the large beaker, and pull it upwards. What happened to the toothpick? Record your observations.
9. Clean up and put away the equirpment you have used.

What Did You Find Out?

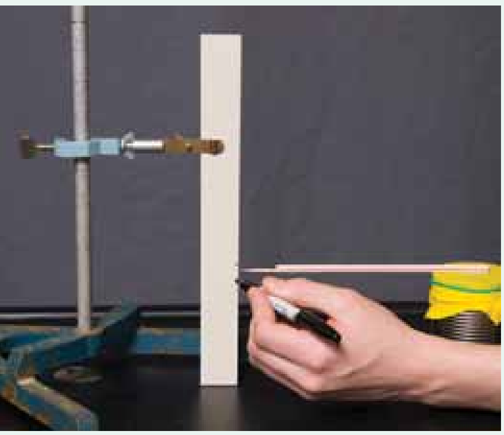
1. (a) In Part 1, what happened to the piece of wood when you hit it?
   (b) Why did this happen?
2. (a) In Part 2, what happened to the toothpick when you pressed down on the top balloon?
   (b) With respect to atmospheric pressure, explain why you think this happened.
3. (a) What happened to the toothpick when you pulled up on the top balloon?
   (b) With respect to atmospheric pressure, explain why you think this happened.

10-2D Build a Barometer

Conduct an INVESTIGATION

Inquiry Focus

Skill Check
- Observing
- Predicting
- Measuring
- Explaining systems



Safety
- Be careful when handling the scissors.

Materials
- balloon
- scissors
- elastic band
- empty soup can or other can with one end removed
- clear adhesive tape
- straw or wooden skewer
- ring stand and clamp
- ruler
- cardboard (about 5 cm × 20 cm)
- felt pen
- outdoor thermometer

Science Skills

Go to Science Skill 2 for information on making observations.

For centuries, barometers have been used to help predict the weather, since changes in atmospheric pressure are associated with changes in weather. In this activity, you will use a barometer to monitor changes in weather. Using data you collect, you will track the weather.

Question
How can a simple barometer be used to forecast weather?

Procedure
1. Cut the balloon open lengthwise with the scissors.
2. Stretch the balloon across the open end of the can. Holding the balloon tightly in place, use the elastic band to secure the balloon to the can. Use clear adhesive tape to ensure the can (your barometer) is well sealed.
3. Cut the straw (or skewer) to a length of 6 cm. Tape the straw to the balloon on the top of the can.
4. Set up the cardboard stand as shown in the photograph. Mark a horizontal line on the cardboard at the height of the straw. This will be the baseline for measuring.
5. Set up your barometer somewhere where it will not be disturbed for a few days. A room with a north-facing window would work best. Do not place the barometer in sunlight or near another heat source, such as a radiator or heat vent.
6. Copy the following data table into your notebook. Give your table a title. Take barometer readings twice a day for at least 5 d. Take one reading about the same time every morning and the second reading about the same time every afternoon.

Day	Time	Barometer Reading (mm)	Up or Down from Previous Reading (mm)	Other Weather Conditions	Outdoor Temperature (°C)
1					
2					

7. In your data table, record the daily outdoor temperature. If you do not have access to an outdoor thermometer, record the temperature given in the local weather report.

Analyze
1. What causes the straw to move up and down?
2. (a) What can you say about the atmospheric pressure if the straw points up?
   (b) What can you say about the atmospheric pressure if the straw points down?
3. Compare the changes in the overall weather with the changes in atmospheric pressure that occurred over the course of your investigation.

Conclude and Apply
1. What does an increase in atmospheric pressure indicate about weather?

Wild, Weird, Wonderful

www Science

Wacky Weather on Other Worlds

Imagine if the weather report predicted a storm expected to last for hundreds of years, with winds five times faster than the average tornado and rainfall so acidic that it could dissolve rock. It might sound like a scenario from the creative imagination of a science fiction writer. In fact, it is a good description of weather that occurs every day on different planets in our solar neighbourhood.

Mars

A Martian windstorm can last months and reach speeds as high as 600 km/h. Rock fragments, pebbles, and dust are whipped around the Martian surface, constantly resculpting its physical features. The following photo shows a Martian dust storm that blanketed the entire planet.

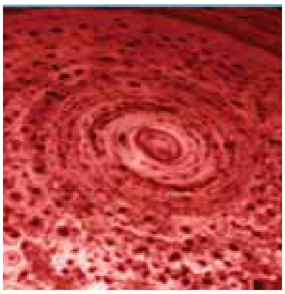
Martian dust storm

Venus

With an atmospheric pressure close to 100 times greater than our own, conditions on Venus are harsh. The atmosphere is 96 percent carbon dioxide gas, and the surface temperature is 460°C. The lower atmosphere contains large amounts of sulfuric acid (H_2SO_4), which can fall as rain. Winds in the middle atmosphere can reach speeds of 720 km/h, but the atmosphere at the Venusian surface is so thick that only a gentle breeze can blow.

Saturn

Hurricanes are among the most energetic and dangerous storms to affect Earth. Ours is not the only planet where hurricanes occur. The National Aeronautics and Space Administration's *Cassini* spacecraft recently sent back pictures of a hurricane-like storm near Saturn's south pole. The monster storm is over 8000 km wide—large enough to cover all of North America. The winds reach speeds of 560 km/h, faster than most tornadoes on Earth. Scientists are not certain what is causing Saturn's storm. Also peculiar is the motion of the storm. On Earth, hurricanes move across the surface as the planet rotates. Saturn's massive storm remains over the same region on the planet.

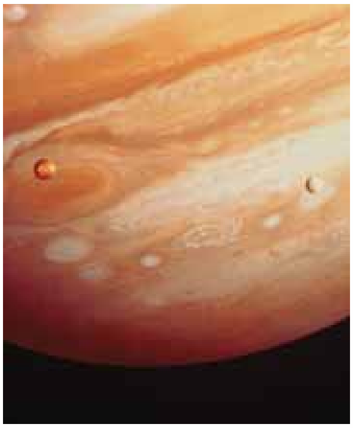


Hurricane-like storm on Saturn

Jupiter

One of the most obvious features on Jupiter is a giant anti-cyclone. An anti-cyclone is a large area of high atmospheric pressure with outward-flowing winds—the opposite of a cyclone or tornado. Scientists believe that the storm, named the Great Red Spot, is occurring on the surface of Jupiter's gaseous shell. The storm is so wide that it spans the width of two to three Earths. Cyclones on Earth typically last several days before they run out of momentum or hit land and lose their energy. This storm on Jupiter has been visible from Earth for over 400 years. The striped pattern of clouds on Jupiter results from churning and upwelling of gases rising from the lower parts of the atmosphere.

The next time you hear a weather report that upsets you, keep in mind that it could be much worse!



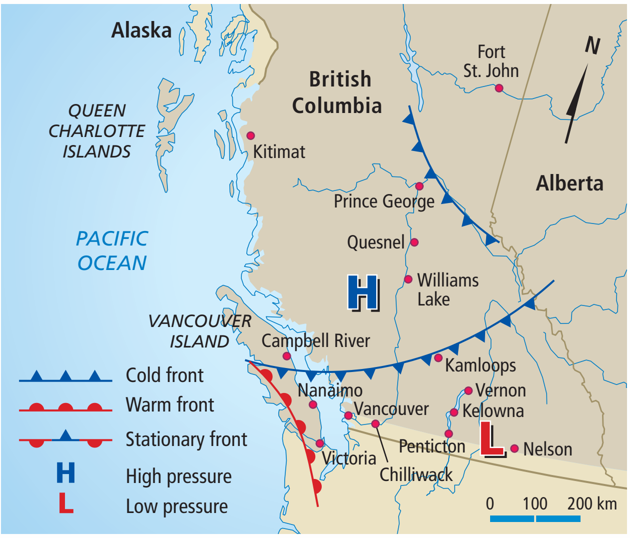
Jupiter's Great Red Spot

Checking Concepts

1. Name the two chemical elements that make up most of Earth's atmosphere.
2. In which layer of the atmosphere do people live?
3. What is atmospheric pressure?
4. What does a barometer measure?
5. What term is used for the amount of water vapour carried in air?
6. What does the Coriolis effect do to winds in the northern hemisphere?
7. What causes jet streams?
8. What is the name for the boundary between air masses?
9. What is the difference between a tornado and a hurricane?
10. Use a Venn diagram to compare "insolation" and "albedo."

Understanding Key Ideas

11. Hot air rises. Why is it that the atmosphere does not get hotter with increasing height? (**Hint:** The explanation is related to the reason why mountain climbers often need to use oxygen tanks.)
12. Explain the role of photosynthetic micro-organisms in the composition of Earth's atmosphere.
13. Explain why 75 percent of the atmosphere's mass is found in the troposphere.
14. Venus and Earth are planets of equal size. The atmosphere of Venus is half the thickness of Earth's atmosphere. Why is the atmospheric pressure at the surface of Venus nearly 100 times greater than atmospheric pressure at the surface of Earth?
15. Why do passenger airplanes often fly just above the troposphere?
16. Explain why sea breezes occur.
17. What factors affect the amount of insolation at Earth's surface?
18. Refer to the weather map below to answer the following questions.



(a) Based on the weather map and the fronts shown, what season do you think it is? Justify your response.
(b) Which direction would you expect the winds to be blowing in Kelowna? Explain.
(c) What type of weather front is approaching Victoria?
(d) Should people in Vernon expect cold or warm weather? Explain.

19. If Earth's oceans were to heat up, how might this affect the atmosphere over the tropics?

Pause and Reflect

You may have heard the old joke "everybody complains about the weather, but nobody does anything about it." If you had super powers that allowed you to do something about the weather, what conditions in the atmosphere would you have to control?

Chapter Review

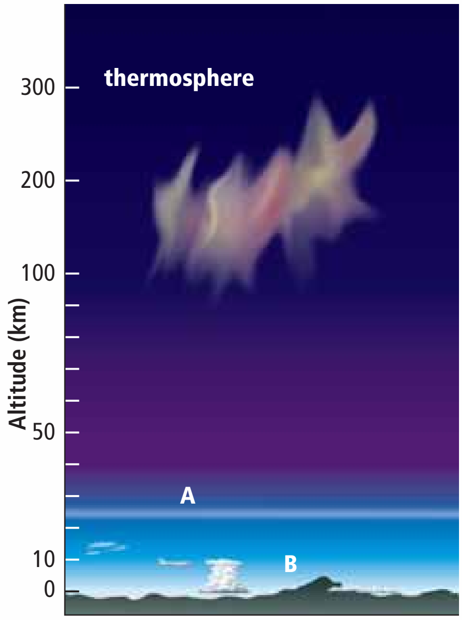
Prepare Your Own Summary

In this chapter, you learned about the transfer of thermal energy in Earth's atmosphere and the role energy transfer plays in atmospheric conditions. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Temperature, Thermal Energy, and Heat
2. Formation and Composition of the Atmosphere
3. Energy Transfer in the Atmosphere

Checking Concepts

1. List the three ways thermal energy is transferred.
2. How does the kinetic molecular theory help to explain the transfer of thermal energy?
3. How is thermal energy transferred through radiation?
4. Use a Venn diagram to compare the processes of conduction and convection.
5. A typical living room in a home can be heated by warm air from a furnace. The warm air rises from the vent and displaces cold air.
   (a) What happens to the warm air after it rises?
   (b) What form of thermal energy transfer heats the room?
6. Which of the following describes a situation in which convection would **not** occur? Justify your response.
   (a) a lake fed by a stream
   (b) a concrete road heated by the Sun
   (c) a snowball warmed in your hand
   (d) a rain cloud passing over a desert
7. Imagine that you are measuring the temperature of freezing water and the thermometer reads 273 degrees. What is the temperature scale of the thermometer?
8. Is the air around us pure oxygen? Explain.
9. Name the layers of the atmosphere indicated by letters in the following diagram.



10. As a substance cools and its thermal energy decreases, what is happening to the motion of the atoms in the substance?

Understanding Key Ideas

11. Is temperature a measure of thermal energy? Explain.
12. Why does atmospheric pressure decrease with increasing height in the atmosphere?
13. How do high pressure areas and low pressure areas create winds?
14. Design and draw a table to compare and contrast high pressure systems with low pressure systems.
15. How does the Coriolis effect differ in the northern and southern hemispheres?
16. The albedo of Earth's surface changes depending on location. Explain why.
17. Compare and contrast tornadoes and hurricanes.

18. Refer to the weather map below to answer the following questions.

(a) Which way is the cold front moving between Vancouver and Williams Lake?
(b) Why should the people of Fort St. John not expect their weather to change for a while?
(c) Colville, Washington, is over 100 km south of Nelson, across the U.S.–Canadian border in Washington State. Colville is experiencing precipitation. What kind of precipitation do you think the city is receiving: rain, snow, or hail? Explain.

19. Some people living several kilometres inland from the ocean say that they can often smell the sea water. Use your understanding of convection to explain why this is possible.

Applying Your Understanding

20. Cities are known to be urban heat islands, with temperatures that are often higher than in surrounding rural and natural vegetated areas. Concrete, asphalt, and roof shingles are some of the surfaces found in a city that readily absorb solar radiation during the day. Later, these materials emit infrared radiation, which raises the air temperature. Furthermore, tall buildings block infrared radiation, keeping it from escaping. Industrial activities and motor vehicle use also help heat up the city environment. To combat the urban heat island problem and promote sustainable building, Metro Vancouver is encouraging people to use building and paving materials with low albedo.
—Adapted from http://www.gvrd.bc.ca/Buildsmart/HeatIslandEffect.htm

(a) How would the albedo of a typical city compare to the albedo of a forested area? Use evidence from the above reading to support your answer.
(b) What would be the best choice of ground cover in order to reduce albedo from a city plaza: asphalt, concrete, or white rock?
(c) Explain your answer to (b).
(d) Which type of roof covering would take the longest to cool down at night: pale-coloured shingles or tar?
(e) Explain your answer to (d).
(f) What is the role of conduction in creating an urban heat island?
(g) What is the role of convection in creating an urban heat island?

Pause and Reflect

Picture the approach of a storm cloud at the edge of a weather front. What is the source of the heat that produced the approaching low pressure system? Create a flowchart showing a possible route for heat transfer starting with the Sun and ending with the storm cloud. Use the terms conduction, convection, and radiation in your answer.