17 Earth's Atmosphere

Big idea

Weather and Climate

Q: What factors determine temperature in the atmosphere?

A hang glider flies over a valley. Skilled hang gliders can fly for hours by making use of air currents.

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.a, ES.1.c, ES.1.e, ES.3.b, ES.11.c, ES.11.d, ES.12.d. **See lessons for details.**

INQUIRY

TRY IT!

MODELING THE ANGLE OF THE SUN

Procedure

1. Place a sheet of dark construction paper on a desk or tabletop. Hold a flashlight approximately 10 cm above the paper. The flashlight should be held at a 90° angle and pointed toward the paper.
2. Darken the room and turn on the flashlight. Have a partner trace the perimeter of the light on the paper.
3. Repeat step 2, but this time, tilt the flashlight so that it is at a 45° angle to the paper. The end of the flashlight should be 10 cm above the paper. Have a partner trace the perimeter of the light on the paper.

Think About It

1. **Observe** Describe the sizes and shapes of the light on the paper for steps 2 and 3.
2. **Model** Suppose the flashlight represents the sun and the paper represents Earth's surface. Which angle gives more energy, per unit area, on the surface of Earth?

17.1 Atmosphere Characteristics

ES.3 The student will investigate and understand the characteristics of Earth and the solar system. Key concepts include **b.** sun-Earth-moon relationships (seasons, tides, and eclipses). **ES.11** The student will investigate and understand the origin and evolution of the atmosphere and the interrelationship of geologic processes, biologic processes, and human activities on its composition and dynamics. Key concepts include **d.** potential changes to the atmosphere and climate due to human, biologic, and geologic activity. Also covered: **ES.12.d.**

Key Questions

How does weather differ from climate?

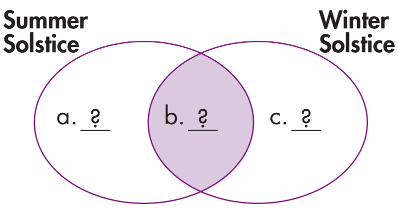
Why do seasonal changes occur?

Vocabulary

- ozone
- troposphere
- stratosphere
- mesosphere
- thermosphere
- summer solstice
- winter solstice
- autumnal equinox
- spring equinox

Reading Strategy

Compare and Contrast
Copy the Venn diagram below. As you read, complete the diagram by comparing and contrasting summer and winter solstices.



EARTH'S ATMOSPHERE is unique. No other planet in our solar system has an atmosphere with the exact mixture of gases or the moisture conditions and heat needed to sustain life as we know it. The gases that make up Earth's atmosphere and the controls to which they are subject are vital to our existence. In this chapter, you will begin to examine the ocean of air in which we live.

The state of the atmosphere at a given time and place is known as *weather.* The combination of Earth's motions and energy from the sun produces a variety of weather. As shown in **Figure 1,** weather influences our everyday activities. **Weather refers to the state of the atmosphere at any given time and place. Weather is constantly changing. Climate, however, is based on observations of weather that have been collected over many years. Climate helps describe all the weather conditions of a place or region.** Climate often is defi ed as "average weather," but this is not a complete description. Climate also includes variations and extremes in weather. For example, farmers need to know the average rainfall during a growing season. But they also need to know the frequency of extremely wet and extremely dry years. The most important measurable properties of weather and climate are air temperature, humidity, type and amount of precipitation, air pressure, and the speed and direction of the wind.

Reading Checkpoint *How does weather differ from climate?*

FIGURE 1 Weather
Washington, D.C., experienced record-breaking snowfalls in back-to-back storms during the winter of 2011.

Composition of the Atmosphere

The composition of the atmosphere has changed dramatically over Earth's nearly 4.6 billion year history. The atmosphere is thought to have started as gases that were emitted during volcanic eruptions. Evidence indicates that oxygen did not start to accumulate in the atmosphere until about 2.5 billion years ago. The atmosphere continues to exchange material with the oceans and life on Earth's surface.

Major Components Sometimes the term *air* is used as if it were a specific gas, which it is not. Air is a mixture of different gases and particles, each with its own physical properties. The composition of air varies from time to time and from place to place. However, if the water vapor, dust, and other variable components were removed from the atmosphere, its makeup would be very stable worldwide up to an altitude of about 80 kilometers.

Look at **Figure 2.** Two gases—nitrogen and oxygen—make up 99 percent of the volume of clean, dry air. Although these gases are the most common components of air, they don't affect the weather much. The remaining 1 percent of dry air is mostly the inert gas argon (0.93 percent) plus tiny quantities of a number of other gases. Carbon dioxide is present in only small amounts (approximately 0.039 percent), but it is an important component of air. Carbon dioxide is an active absorber of energy given off y Earth. Therefore, it plays a significant role in heating the atmosphere.

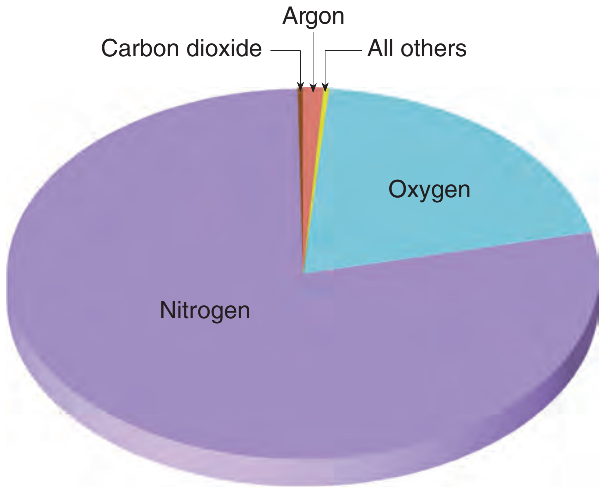


FIGURE 2 Volume of Clean, Dry Air Nitrogen and oxygen dominate the volume of gases composing dry air.

Variable Components Important materials that vary in the air from time to time and place to place include water vapor, dust particles, and ozone. These components also can have significant effects on weather and climate.

The amount of water vapor varies from almost none to about 4 percent by volume. Why is such a small quantity so significant? **Water vapor is the source of all clouds and precipitation. Like carbon dioxide, water vapor absorbs heat given off y Earth. It also absorbs some solar energy.**

Movements of the atmosphere allow a large quantity of solid and liquid particles to be suspended within it. Although visible dust sometimes clouds the sky, these relatively large particles are too heavy to stay in the air for very long. Still, many particles are microscopic and remain suspended for longer periods of time. These particles include sea salts from breaking waves, fi e soil blown into the air, smoke and soot from fi es, pollen and microorganisms lifted by the wind, dust from meteorites, and ash and dust from volcanic eruptions.

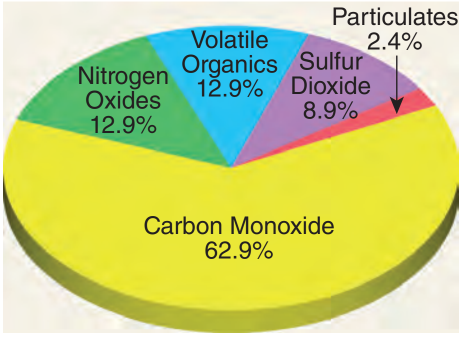


FIGURE 3 Primary Pollutants in the Atmosphere This circle graph shows major primary pollutants for the United States in 2008. Percentages are calculated by weight. Source: U.S. Environmental Protection Agency.

PLANET DIARY

For links on the **Atmosphere**, visit PlanetDiary.com/HSES.

Another important variable component of the atmosphere is ozone. **Ozone** is a form of oxygen that combines three oxygen atoms into each molecule (O_3). Ozone is not the same as the oxygen we breathe, which has two atoms per molecule (O_2). There is very little ozone in the atmosphere, and it is not distributed evenly. It is concentrated in a layer located between 10 and 50 kilometers above Earth's surface. Ozone can also be found near ground level. However, ground-level ozone is an air pollutant.

At 10 to 50 kilometers above Earth's surface, oxygen molecules (O_2) are split into single atoms of oxygen (O) when they absorb ultraviolet (UV) radiation emitted by the sun. Ozone is then produced when a single atom of oxygen (O) and a molecule of oxygen (O_2) collide. Ozone is concentrated in this altitude range because the UV radiation from the sun is sufficient to produce single atoms of oxygen. In addition, there are enough gas molecules to bring about the required collisions.

The ozone layer is crucial to life on Earth. Ozone absorbs potentially harmful UV radiation from the sun. **If ozone did not filter most UV radiation and all of the sun's UV rays reached the surface of Earth, our planet would be uninhabitable for many living organisms.**

Human Influence Air pollutants are airborne particles and gases that occur in concentrations large enough to endanger the health of organisms. Primary pollutants, shown in **Figure 3,** are emitted directly from identifiable sources. Emissions from transportation vehicles account for nearly half the primary pollutants by weight.

Secondary pollutants are not emitted directly into air. They form in the atmosphere when reactions take place among primary pollutants and other substances. For example, after the primary pollutant sulfur dioxide enters the atmosphere, it combines with oxygen to produce sulfur trioxide. Then the sulfur trioxide combines with water to create sulfuric acid, an irritating and corrosive substance. Rain that contains high amounts of sulfuric acid is called acid rain. Acid rain can be harmful to forests and aquatic life in lakes and streams.

Reactions triggered by strong sunlight are called *photochemical reactions.* For instance, when nitrogen oxides absorb solar radiation, a chain of complex reactions begins. If certain volatile organic compounds are present, secondary products form that are reactive, irritating, and toxic. This noxious mixture of gases and particles is called *photochemical smog.* Ground-level ozone is also a component of photochemical smog.

Reading Checkpoint *What are secondary pollutants?*

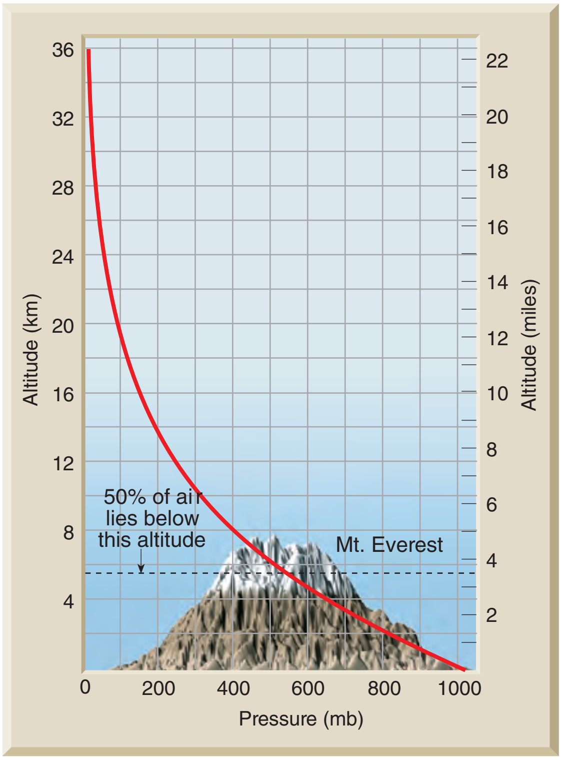


FIGURE 4 Atmospheric Pressure vs. Altitude
This graph shows how atmospheric pressure varies with altitude.
Compare *How do changes in air pressure at low altitudes compare with air pressure changes at high altitudes?*

Height and Structure of the Atmosphere

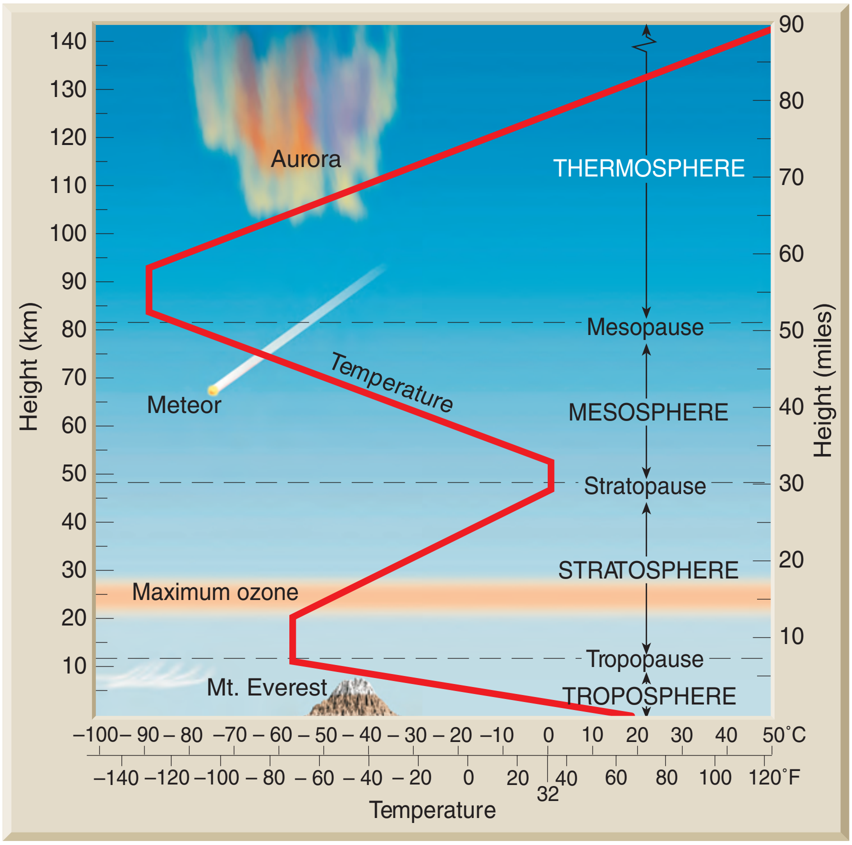
Where does the atmosphere end and outer space begin? There is no sharp boundary. **The atmosphere thins as you travel away from Earth until there are too few gas molecules to detect.**

Pressure Changes To understand the vertical extent of the atmosphere, examine **Figure 4,** which shows changes in atmospheric pressure with height. Atmospheric pressure is caused by the weight of the air above. At sea level, the average pressure is slightly more than 1000 millibars, or slightly more than 1 kilogram per square centimeter. One half of the atmosphere by mass lies below an altitude of 5.6 kilometers. Above 100 kilometers, only 0.00003 percent of all the gases making up the atmosphere exist.

Temperature Changes The pictures of snow-capped mountains rising above snow-free valleys shown in **Figure 5** might remind you that Earth's atmosphere becomes colder as you climb higher. But not all layers of the atmosphere show this temperature pattern.

FIGURE 5 Atmospheric Temperature Changes
In Jasper National Park in Alberta, Canada, snowy mountaintops contrast with warmer, snow-free lowlands below.

FIGURE 6 Thermal Structure of the Atmosphere The change in air temperature within a layer of the atmosphere is different for each of the four layers of the atmosphere. **Interpret** ***How do air temperatures change with height in the mesosphere?***



The atmosphere can be divided vertically into four layers based on temperature. Figure 6 illustrates these layers. The bottom layer, where temperature decreases with an increase in altitude, is the **troposphere.** It is in this layer that essentially all important weather phenomena occur. The thickness of the troposphere is not the same everywhere. It varies with latitude and the season. On average, the temperature drop continues to a height of about 12 kilometers, where the outer boundary of the troposphere, called the *tropopause,* is located.

Beyond the tropopause is the **stratosphere.** In the stratosphere, the temperature remains constant to a height of about 20 kilometers. It then begins a gradual increase in temperature that continues until the *stratopause,* at a height of nearly 50 kilometers above Earth's surface. Temperatures increase in the stratosphere because the atmosphere's ozone is concentrated here. Recall that ozone absorbs ultraviolet radiation from the sun. As a result, the stratosphere is heated.

In the third layer, the **mesosphere,** temperatures again decrease with height until the *mesopause.* The mesopause is more than 80 kilometers above the surface and the temperatures approach −90°C. The fourth layer extends outward from the mesopause and has no well-defined upper limit. It is the **thermosphere,** a layer that contains only a tiny fraction of the atmosphere's mass. Temperatures increase in the thermosphere because oxygen and nitrogen absorb short-wave, high-energy solar radiation.

Earth-Sun Relationships

Nearly all of the energy that drives Earth's variable weather and climate comes from the sun. Earth absorbs only a tiny percentage of the energy given off y the sun—less than one two-billionth. This may seem insignificant, but the amount is several hundred thousand times the electrical-generating capacity of the United States.

Solar energy is not distributed evenly over Earth's surface. The amount of energy received varies with latitude, time of day, and season. These variations in solar heating are caused by the motions of Earth relative to the sun and by variations in Earth's land and ocean surface. It is the unequal heating of Earth that creates winds and drives the ocean's currents. These movements transport heat from the tropics toward the poles, thus driving the phenomena we call weather.

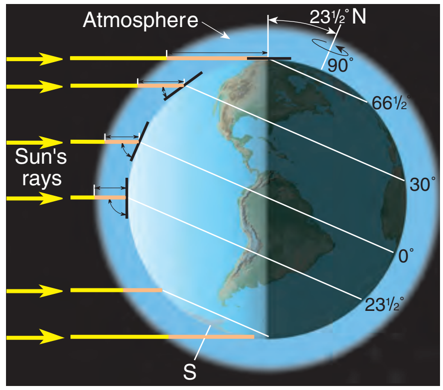


FIGURE 7 Tilt of Earth's Axis Earth's axis always points toward the North Star as it revolves around the sun. Rays striking Earth at a low angle (toward the poles) must travel through more of the atmosphere than rays striking at a high angle (around the equator).

Earth's Motions Earth has two principal motions—rotation and revolution. *Rotation* is the spinning of Earth about its axis. The axis is an imaginary line running through the north and south poles. Our planet rotates once every 24 hours, producing the daily cycle of daylight and darkness. *Revolution* is the movement of Earth in its orbit around the sun. Earth travels at nearly 113,000 kilometers per hour in an elliptical orbit about the sun.

Earth's Orientation and Seasons We know that it is colder in the winter than in the summer. But why? Length of day and a gradual change in the angle of the noon sun above the horizon affect the amount of energy Earth receives. **Seasonal changes occur because Earth's position relative to the sun continually changes as it travels along its orbit.** Earth's axis is not perpendicular to the plane of its orbit around the sun. Instead it is tilted 23.5 degrees from the perpendicular, as shown in **Figure 7.** Because the axis remains pointed toward the North Star as Earth moves around the sun, the position of Earth's axis relative to the sun's rays is constantly changing. If the axis were not tilted, we would not have seasonal changes.

Sun's Apparent Path The changing orientation of Earth relative to the sun causes the sun's apparent path to vary with latitude and season. The angle of the noon sun can vary by up to 47 degrees (−23.5 degrees to +23.5 degrees) for many locations during the year. A mid-latitude city like New York, located about 40 degrees north latitude, has a maximum noon sun angle of 73.5 degrees when the sun's vertical rays reach their farthest northward location in June. Six months later, New York has a minimum noon sun angle of 26.5 degrees.

Reading Checkpoint *In which direction does Earth's axis point?*

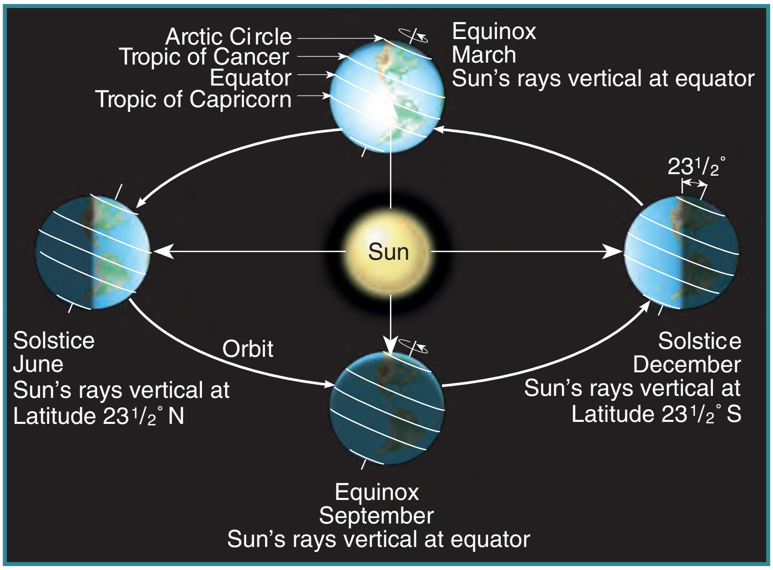


FIGURE 8 Solstices and Equinoxes The solstices and equinoxes mark the beginning of the four seasons: summer, fall, winter, and spring. The sun's rays are vertical at 23.5 degrees north latitude on June 20 or 21. This accounts for the warm temperatures of the summer season in the Northern Hemisphere.

Solstices and Equinoxes On or around June 20 or 21 each year, Earth's axis is such that the Northern Hemisphere is "leaning" 23.5 degrees toward the sun, as shown on the left ide of **Figure 8.** This date is known as the **summer solstice,** or the fi st "official" day of summer. Six months later, in December, when Earth has moved to the opposite side of its orbit, the Northern Hemisphere leans 23.5 degrees away from the sun. December 21 or 22 is the **winter solstice,** the fi st day of winter. On days between these extremes, Earth's axis is leaning at amounts less than 23.5 degrees to the rays of the sun.

The equinoxes occur midway between the solstices. September 22 or 23 is the date of the **autumnal equinox** and the start of autumn in the Northern Hemisphere. The **spring equinox** occurs on or around March 19 or 20, and it marks the start of spring for the Northern Hemisphere. On these dates, the vertical rays of the sun strike the equator (0 degrees latitude) because Earth is in a position in its orbit such that the axis is tilted neither toward nor away from the sun.

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Length of Daylight The length of daylight compared to darkness also is determined by Earth's position in orbit. All latitudes receive 12 hours of daylight during the vernal (spring) and autumnal equinoxes (equal night). The length of daylight on the summer solstice in the Northern Hemisphere is greater than the length of darkness. The farther you are north of the equator on the summer solstice, the longer the period of daylight. When you reach the Arctic Circle, at 66.5 degrees north latitude, daylight lasts 24 hours.

17.1 Assessment

Review Key Concepts

1. Compare and contrast weather and climate.
2. Why do seasonal changes occur?
3. How much of Earth's atmosphere is located below about 5.6 kilometers?
4. How do ozone molecules form in the stratosphere?
5. In which layers of the atmosphere does temperature increase with increasing height?

Think Critically

6. **Apply Concepts** Explain what would happen to air temperatures in the troposphere if carbon dioxide were removed from air.

CONNECTING CONCEPTS

7. **Explain** Using Figure 8, explain why the summer and winter solstices and the spring and autumnal equinoxes occur at opposite times in the Northern and Southern hemispheres.

17.2 Heating the Atmosphere

ES.12 The student will investigate and understand that energy transfer between the sun and Earth and its atmosphere drives weather and climate on Earth. Key concepts include **d.** weather phenomena and the factors that affect climate including radiation, conduction, and convection. Also covered: **ES.11.c.**

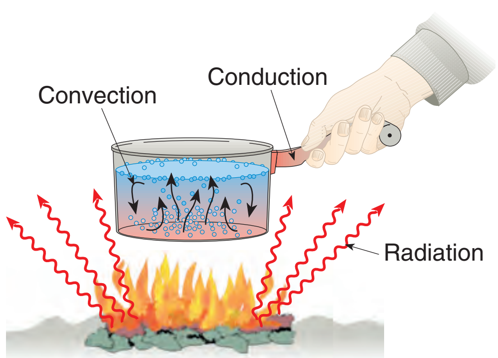
THE CONCEPTS of heat and temperature often are confused. The phrase "in the heat of the day" is one common expression in which the word "heat" is misused to describe the concept of temperature. **Heat is the energy transferred from one object to another because of a difference in their temperatures.** All matter is composed of atoms or molecules that possess *kinetic energy*, or the energy of motion. **Temperature** is a measure of the average kinetic energy of the individual atoms or molecules in a substance. When energy is transferred to the gas atoms and molecules in air, those particles move faster and air temperature rises. When air transfers energy to a cooler object, its particles move more slowly, and air temperature drops.

Energy Transfer as Heat

Th ee mechanisms of energy transfer as heat are conduction, convection, and radiation. All three processes, illustrated in **Figure 9,** happen simultaneously in the atmosphere. These mechanisms operate to transfer energy between Earth's surface (both land and water) and the atmosphere.

Conduction Anyone who has touched a metal spoon that was left in a hot pan has experienced the result of heat conducted through the spoon. **Conduction** is the transfer of heat through matter by molecular activity. The energy of molecules is transferred by collisions from one molecule to another. Heat flows from the higher temperature matter to the lower temperature matter.

FIGURE 9 Energy Transfer as Heat A pot of water on the campfire illustrates the three mechanisms of heat transfer.



Key Questions

How are heat and temperature related?

What are the three major mechanisms of heat transfer?

How is the atmosphere affected by each of the heat transfer mechanisms?

Vocabulary

- heat
- temperature
- conduction
- convection
- radiation
- reflection
- scattering
- greenhouse effect

Reading Strategy

Use Prior Knowledge Before you read, copy the table below and write your definition for each vocabulary term. After you read, write the scientific definition of each term and compare it with your original definition.

Term	Your Definition	Scientific Definition
Heat	a. ?	b. ?
Temperature	c. ?	d. ?

The ability of substances to conduct heat varies greatly. Metals are good conductors, as those of us who have touched hot metal have quickly learned. Air, however, is a very poor conductor of heat. Because air is a poor conductor, conduction is important only between Earth's surface and the air directly in contact with the surface. For the atmosphere as a whole, conduction is the least important mechanism of heat transfer.

Convection Much of the heat transfer that occurs in the atmosphere is carried on by convection. **Convection** is the transfer of heat by mass movement or circulation within a substance. It takes place in fluids, such as the ocean and air, where the atoms and molecules are free to move about. Convection also takes place in solids, such as Earth's mantle, that behave like fluids over long periods.

The pan of water in Figure 9 shows circulation by convection. Radiation from the fi e warms the bottom of the pan, which conducts heat to the water near the bottom of the container. As the water is heated, it expands and becomes less dense than the water above. The warmer, less dense water rises above the cooler water. At the same time, cooler, denser water near the top of the pan sinks to the bottom, where it becomes heated. As long as the water is heated unequally, it will continue to circulate. In much the same way, most of the heat acquired by radiation and conduction in the lowest layer of the atmosphere is transferred by convective fl w.

Reading Checkpoint *What is convection?*

Electromagnetic Waves The sun is the ultimate source of energy that causes our weather. Visible light, radiant heat energy, and ultraviolet rays from the sun are some of the forms of energy in the electromagnetic (EM) spectrum, shown in **Figure 10.** All of the radiation in this spectrum consists of electromagnetic waves. Electromagnetic waves consist of changing electric and magnetic fi lds. The source of all electromagnetic waves is vibrating charges. Although different types of EM waves have different energies, they all travel through the vacuum of space at 300,000 kilometers per second. They travel only slightly slower through our atmosphere.

FIGURE 10
Electromagnetic Spectrum
Electromagnetic energy is classified according to wavelength in the electromagnetic spectrum.

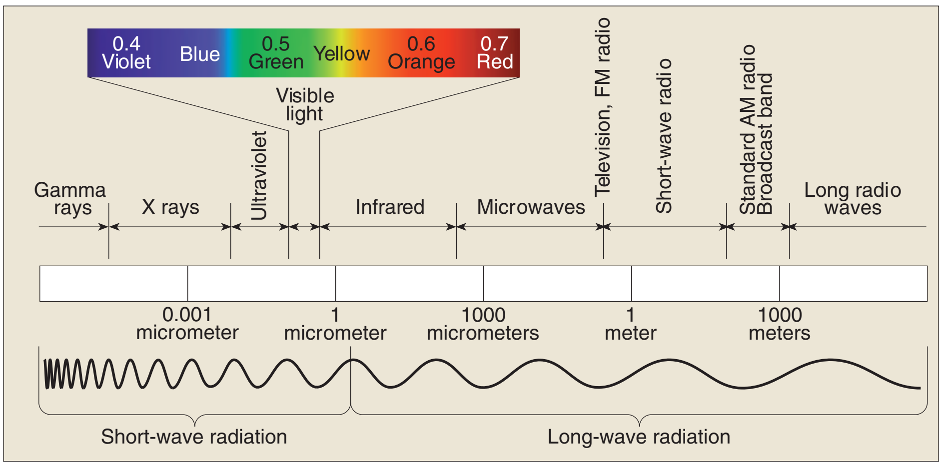


FIGURE 11 Visible Light Visible light consists of an array of colors commonly called the colors of the rainbow.

Imagine what happens when you toss a pebble into a pond. Ripples are made and move away from the location where the pebble hit the water's surface. Much like these ripples, electromagnetic waves move out from their source and come in various sizes. Electromagnetic waves are classified by their wavelength, or the distance from one crest to the next. Radio waves have the longest wavelengths, ranging to tens of kilometers. Gamma waves are the shortest, and are less than a billionth of a centimeter long.

Visible light is the only portion of the electromagnetic spectrum you can see. White light is really a mixture of colors, as shown in the rainbow in **Figure 11.** Each color corresponds to a specific wavelength. By using a prism, white light can be divided into the colors of the rainbow, from violet with the shortest wavelength—0.4 micrometer—to red with the longest wavelength—0.7 micrometer (1 micrometer is 0.0001 centimeter).

Radiation The third mechanism of heat transfer is radiation, as shown in Figure 9. **Radiation** travels out in all directions from its source. **Unlike conduction and convection, which need material to travel through, the transfer of heat energy by radiation can occur through the vacuum of space.** Solar energy reaches Earth by radiation.

To understand how the atmosphere is heated, it is useful to think about four laws governing radiation.

1. **All objects, at any temperature, emit radiant energy.** Not only hot objects like the sun but also Earth—including its polar ice caps—continually emit radiant energy.
2. **Hotter objects radiate more total energy per unit area than colder objects do.**
3. **Th hottest radiating bodies produce the shortest wavelengths of maximum radiation.** For example, the sun, with a surface temperature of nearly 6000°C, radiates maximum energy at 0.5 micrometers, which is in the visible range. The maximum radiation for Earth occurs at a wavelength of 10 micrometers, well within the infrared range.
4. **Objects that are good absorbers of radiation are good emitters as well.** Gases are selective absorbers and radiators. The atmosphere does not absorb certain wavelengths of radiation, but it is a good absorber of other wavelengths.

FIGURE 12 Solar Radiation
This diagram shows what happens, on average, to incoming solar radiation by percentage.

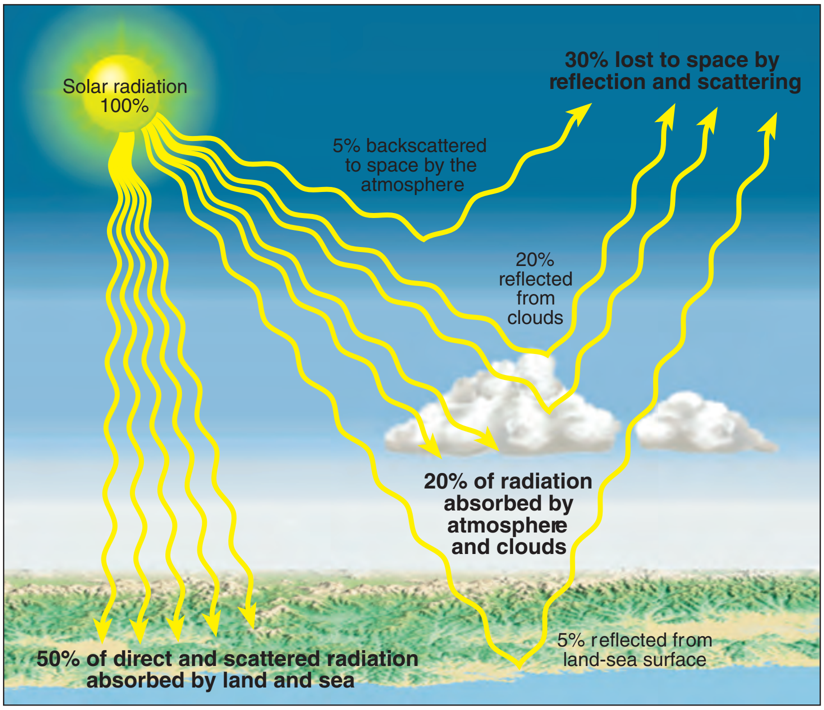
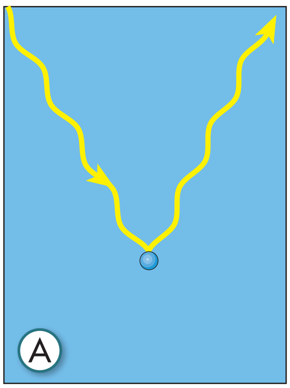
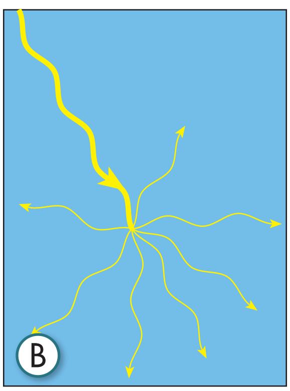


FIGURE 13
Reflection vs. Scattering
A Reflected light bounces back with the same intensity.



B Scattering produces more light rays with a weaker intensity.



What Happens to Solar Radiation?

When radiation strikes an object, there usually are three different results.

1. **Some energy is absorbed by the object.** When radiant energy is absorbed, it is converted to heat and causes a temperature increase.
2. **Substances such as water and air are transparent to certain wavelengths of radiation.** These substances transmit the radiant energy. Radiation that is transmitted does not contribute energy to the object.
3. **Some radiation may bounce off t e object without being absorbed or transmitted.** **Figure 12** shows what happens to incoming solar radiation, averaged for the entire globe.

Reflection and Scattering **Reflectio** occurs when an electromagnetic wave bounces off n object. The reflected radiation has the same intensity as the incident radiation. In contrast, **scattering** produces a larger number of weaker rays that travel in different directions, as shown in **Figure 13.** Scattering disperses waves both forward and backward. However, more energy is dispersed in the forward direction. About 30 percent of the solar energy reaching the outer atmosphere is reflected back to space. This 30 percent includes the amount of energy sent skyward by scattering. This energy is lost and does not heat Earth's atmosphere.

Small dust particles and gas molecules in the atmosphere scatter some incoming radiation in all directions. This explains how light reaches into the area beneath a shade tree, and how a room is lit in the absence of direct sunlight. Scattering also accounts for the brightness and even the blue color of the daytime sky. About half of the solar radiation that is absorbed at Earth's surface arrives as scattered radiation.

Absorption About 50 percent of the solar energy that strikes the top of the atmosphere reaches Earth's surface and is absorbed, as shown in Figure 12. Most of this energy is then reradiated skyward.

The atmosphere efficiently absorbs the longer wavelengths emitted by Earth. Water vapor and carbon dioxide are the major absorbing gases. When a gas molecule absorbs these waves, this energy is transformed into molecular motion that can be detected as a rise in temperature. Gases in the atmosphere eventually radiate some of this energy away. Some energy travels skyward, where it may be reabsorbed by other gas molecules. The rest travels earthward and is again absorbed. In this way, Earth's surface is continually supplied with heat from the atmosphere as well as from the sun.

Without these absorbing gases in our atmosphere, Earth would not be a suitable habitat for most types of living things on Earth today. This phenomenon has been termed the **greenhouse effect** because it was once thought that greenhouses were heated in a similar manner. (A more important factor in keeping a greenhouse warm is that the greenhouse itself prevents the mixing of air inside with cooler air outside.)

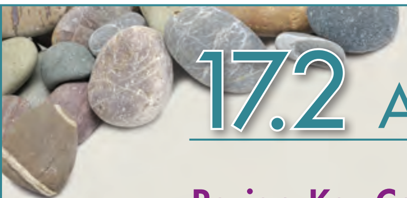
There is an overall balance of energy transfer into and out of Earth's atmosphere. Over time, incoming solar radiation is absorbed, reflected, or reradiated. As a result, the atmosphere's average temperature tends to remain constant from year to year. But the atmosphere's average temperature can and does change. It changes if there are factors that disturb its energy balance.

Photosynthesis Some incoming solar radiation is not absorbed or reradiated. Instead, plants and some other living things use the energy from this radiation in photosynthesis. Thus solar energy is the main energy source for virtually all life on Earth.

INQUIRY APPLY IT!

Q: *Isn't the greenhouse effect responsible for global warming?*

A: It is important to note that the greenhouse effect and global warming *are not* the same thing. Without the greenhouse effect, Earth would be mostly uninhabitable. We do have mounting evidence that human activity (particularly the release of carbon dioxide into the atmosphere) is responsible for a rise in global temperatures. Thus, human activities seem to be enhancing an otherwise natural process (the greenhouse effect) to increase Earth's temperature. Nevertheless, to equate the greenhouse effect, which makes life possible, with undesirable changes to our atmosphere caused by human activity is incorrect.



17.2 Assessment

Review Key Concepts

1. How are heat and temperature related?
2. List and describe the three major mechanisms of heat transfer in the atmosphere.
3. How is the atmosphere affected by
   a. convection?
   b. conduction?
   c. radiation?
4. Describe what happens to solar radiation when it strikes an object.
5. Contrast reflection and scattering.

Think Critically

6. **Apply Concepts** Dark objects tend to absorb more radiation than light-colored objects. Explain whether dark objects or light objects on Earth's surface would be better radiators of heat.

WRITING IN SCIENCE

7. **Describe** Write a paragraph that describes the four laws governing radiation. Use examples wherever possible.

BIGIDEA WEATHER AND CLIMATE

8. **Relate Cause and Effect** Explain how radiation from the sun affects Earth's climate.

17.3 Temperature Controls

ES.11 The student will investigate and understand the origin and evolution of the atmosphere and the interrelationship of geologic processes, biologic processes, and human activities on its composition and dynamics. Key concepts include **c.** atmospheric regulation mechanisms including the effects of density differences and energy transfer.

Key Questions

What is a temperature control?

How do the heating of land and water differ?

Why do some clouds reflect a portion of sunlight back to space?

Vocabulary

- albedo
- isotherm

Reading Strategy

Preview Copy the table below. Before you read, use Figure 15 to describe the temperature variations for Vancouver and Winnipeg.

Temperature Variations	
Vancouver	a. ___?___
Winnipeg	b. ___?___

TEMPERATURE IS ONE of the basic elements of weather and climate. When someone asks what it is like outside, air temperature is often the fi st element we mention. At a weather station, the temperature is read on a regular basis from instruments mounted in an instrument shelter similar to the one in **Figure 14.** The shelter protects the instruments from direct sunlight and allows a free flow of air.

Why Temperatures Vary

A temperature control is any factor that causes temperature to vary from place to place and from time to time. Earlier in this chapter you examined the most important cause for temperature variations—differences in the receipt of solar radiation. Because variations in the angle of the sun's rays and length of daylight depend on latitude, they are responsible for warmer temperatures in the tropics and colder temperatures toward the poles. Seasonal temperature changes happen as the sun's vertical rays move toward and away from a particular latitude during the year. **Factors other than latitude that exert a strong influence on temperature include differences in the heating of land and water, altitude, geographic position, cloud cover, and ocean currents.**

Reading Checkpoint *List three factors that influence temperature.*

FIGURE 14
Measuring Temperature
This instrument shelter contains an electrical thermometer called a thermistor.

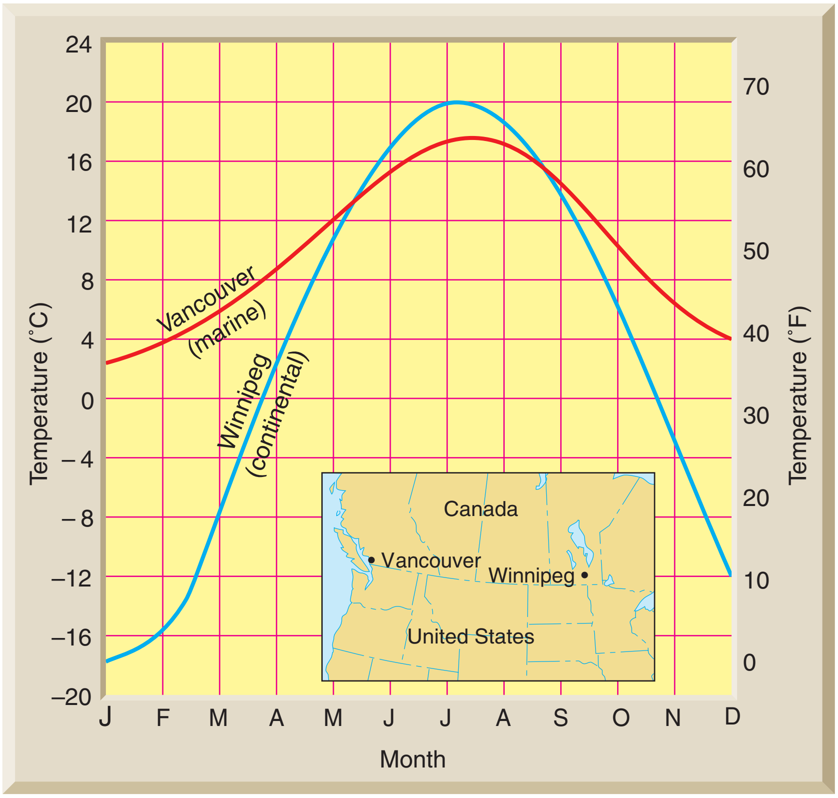


FIGURE 15 Mean Monthly Temperatures for Vancouver and Winnipeg Winnipeg illustrates the greater extremes associated with an interior location. **Calculate** *How much lower is Winnipeg's January mean temperature than Vancouver's? Calculate the temperature to the nearest degree.*

Land and Water The heating of Earth's surface controls the temperature of the air above it. To understand variations in air temperature, we consider the characteristics of the surface. Different land surfaces absorb varying amounts of incoming solar energy. The largest contrast, however, is between land and water. **Land heats more rapidly and to higher temperatures than water. Land also cools more rapidly and to lower temperatures than water.** Temperature variations, therefore, are considerably greater over land than over water.

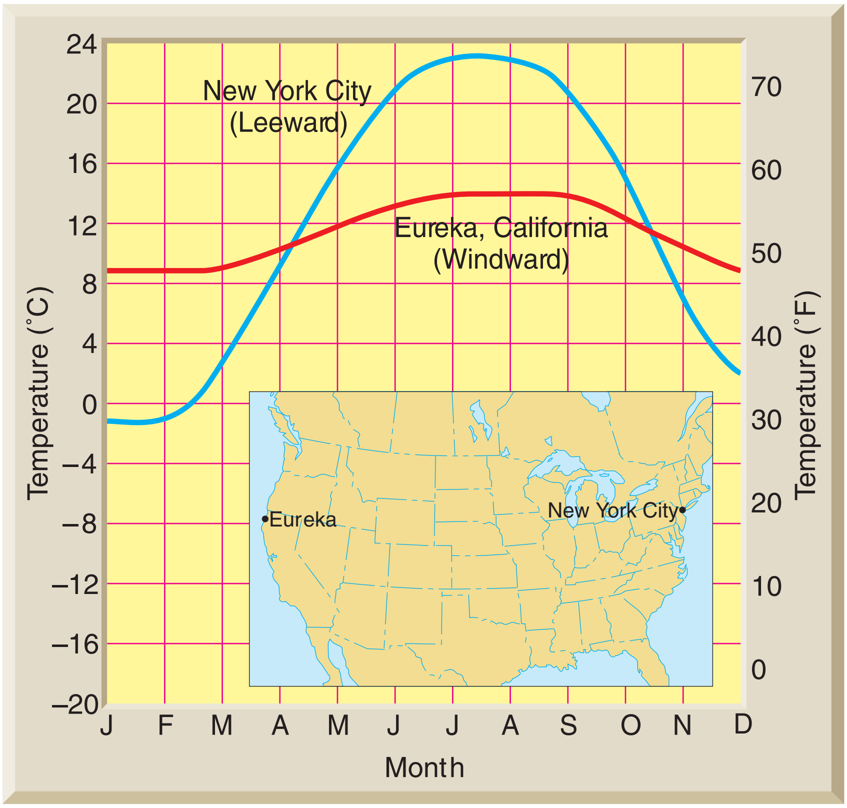
Monthly temperature data for two cities, shown in **Figure 15,** show the influence of a large body of water. Vancouver, British Columbia, is located along the Pacific coast and receives winds off he Pacific Ocean. Winnipeg, Manitoba, is far from the influence of water. Both cities are at about the same latitude, so they experience similar lengths of daylight and angles of the sun's rays. Winnipeg, however, has much greater temperature extremes than Vancouver does. Vancouver's moderate year-round climate is due to its location by the Pacific Ocean.

Temperature variations in the Northern and Southern hemispheres are compared in **Table 1.** Water accounts for 61 percent of the Northern Hemisphere, and land accounts for the remaining 39 percent. In the Southern Hemisphere, 81 percent of the surface is water and only 19 percent of the surface is land. Because the Southern Hemisphere has a greater percentage of surface water, it shows smaller annual temperature variations than the Northern Hemisphere.

Table 1 Variation in Annual Mean Temperature Range with Latitude

Latitude	Northern Hemisphere (°C)	Southern Hemisphere (°C)
0	0	0
15	3	4
30	13	7
45	23	6
60	30	11
75	32	26
90	40	31

FIGURE 16 Mean Monthly Temperatures for Eureka and New York City Eureka is strongly influenced by prevailing ocean winds, and New York City is not.



Geographic Position The geographic setting can greatly influence local temperatures. A coastal location where prevailing winds blow from the ocean onto the shore is called a windward coast. A windward coast experiences considerably different temperatures than does a coastal location where the prevailing winds blow from the land toward the ocean (a leeward coast). A windward coast will experience the full moderating influence of the ocean—cool summers and mild winters, compared to an inland station at the same latitude. In contrast, a leeward coast will have a more continental temperature pattern because winds do not carry the ocean's influence onshore. Eureka, California, and New York City illustrate this effect, as shown in **Figure 16.** The annual temperature range in New York City is 19°C greater than Eureka's range.

Seattle and Spokane, both in the state of Washington, illustrate another aspect of geographic position—mountains that act as barriers. Although Spokane is only about 360 kilometers east of Seattle, the towering Cascade Range separates the cities. As a result, Seattle's temperatures show a marine influence, but Spokane's are more typically continental, as shown in **Figure 17.** Spokane is 7°C cooler than Seattle in January and 4°C warmer than Seattle in July. The annual range in Spokane is 11°C greater than in Seattle. The Cascade Range cuts Spokane off rom the moderating influence of the Pacific Ocean.

Altitude Two cities in Ecuador, Quito and Guayaquil, demonstrate the influence of altitude on mean temperature. Both cities are near the equator and relatively close to one another, as shown in **Figure 18.**

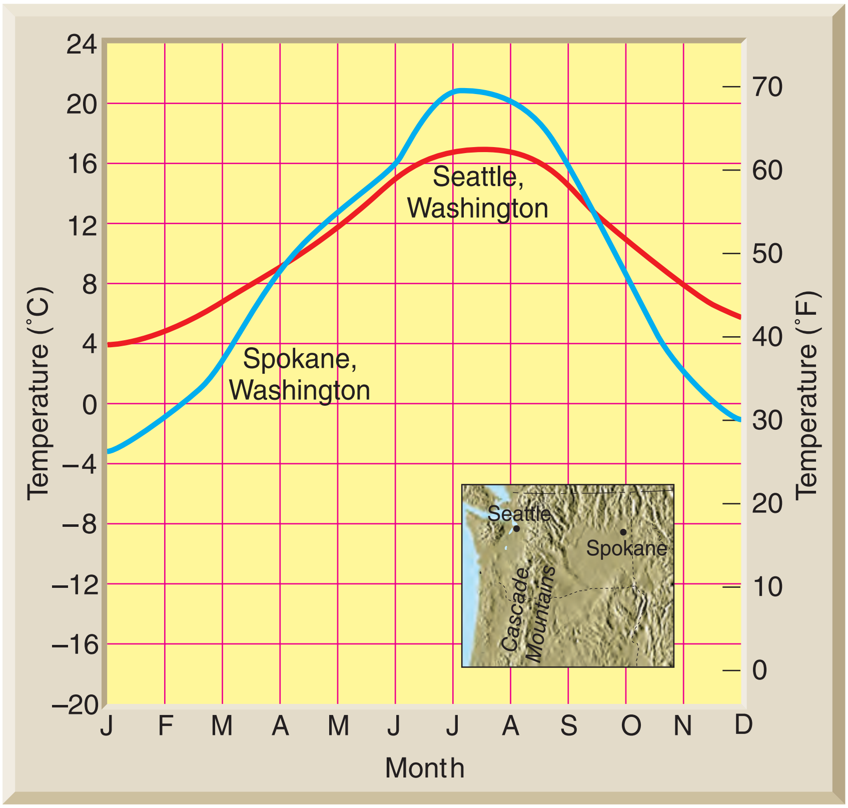


FIGURE 17 Mean Monthly Temperatures for Seattle and Spokane The Cascade Mountains cut off Spokane from the moderating influence of the Pacific Ocean. **Interpret Graphs** ***How does this affect Spokane's annual temperature range?***

The annual mean temperature at Guayaquil is 25°C, compared to Quito's mean of 13°C. If you note these cities' elevations, you can understand the temperature difference. Guayaquil is only 12 meters above sea level, whereas Quito is high in the Andes Mountains at 2800 meters.

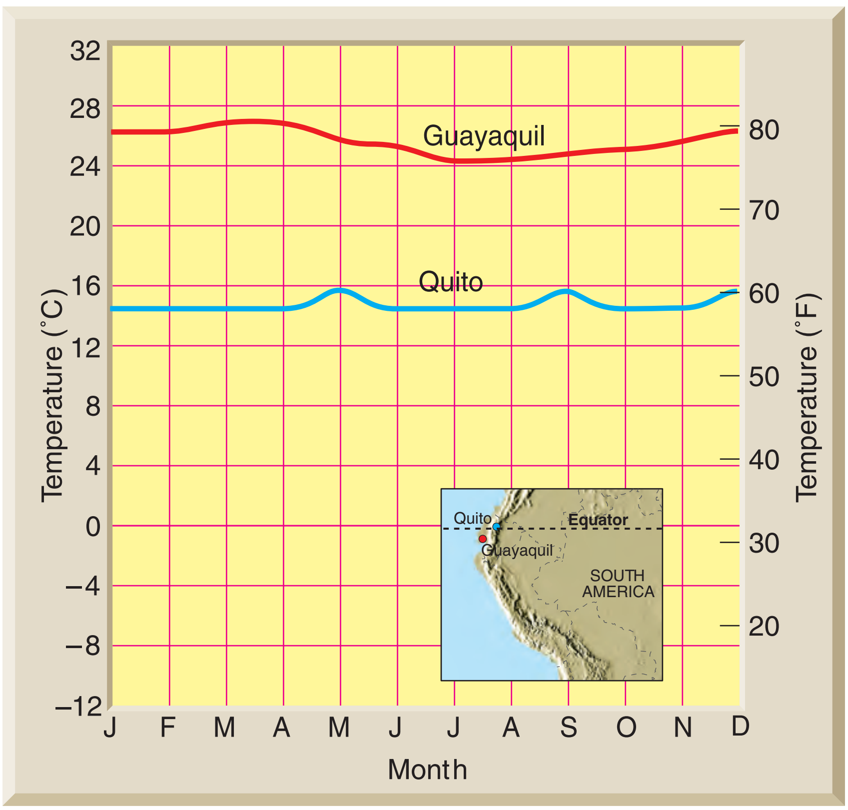
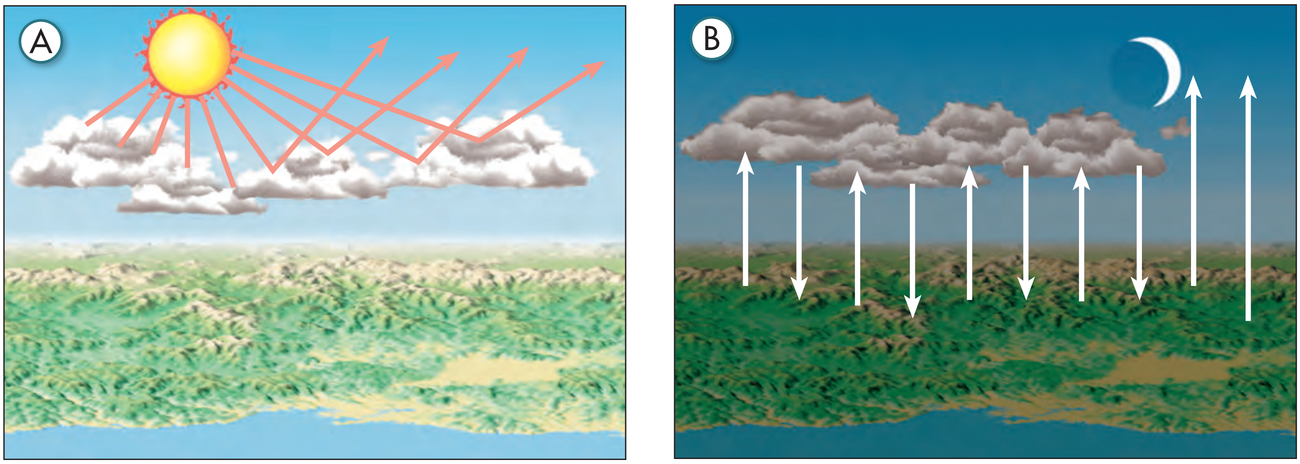


FIGURE 18 Mean Monthly Temperatures for Quito and Guayaquil Quito's altitude is much higher than Guayaquil's, causing Quito to experience cooler temperatures than Guayaquil.

FIGURE 19 **Cloud Cover**



A During daylight hours, clouds reflect solar radiation back to space.

B At night, clouds absorb radiation from the land and reradiate some of it back to Earth, increasing nighttime temperatures.

Cloud Cover and Albedo **Albedo** is the fraction of total radiation that is reflected by any surface. **Many clouds have a high albedo, and therefore reflect a significant portion of the sunlight that strikes them back to space.** The extent of cloud cover is a factor that influences temperatures in the lower atmosphere. Since clouds reduce the amount of incoming solar radiation, the maximum temperatures on a cloud-covered day will be lower than on a day when the clouds are absent and the sky is clear, as shown in **Figure 19A.**

At night, clouds have the opposite effect, as shown in **Figure 19B.** Clouds act as a blanket by absorbing outgoing radiation emitted by Earth and reradiating a portion of it back to the surface. Thus, nighttime air temperatures do not drop as low on a cloudy night compared to a clear night. The overall effect of cloud cover reduces the daily temperature range by lowering the daytime maximum temperature and raising the nighttime minimum temperature.

World Distribution of Temperature

Take a moment to study **Figure 20,** which is a world isothermal map. **Isotherms** are lines that connect points that have the same temperature. From hot colors near the equator to cool colors toward the poles, this map shows mean sea-level temperatures in the seasonally extreme month of July. All temperatures on this map have been reduced to sea level to eliminate complications caused by differences in altitude.

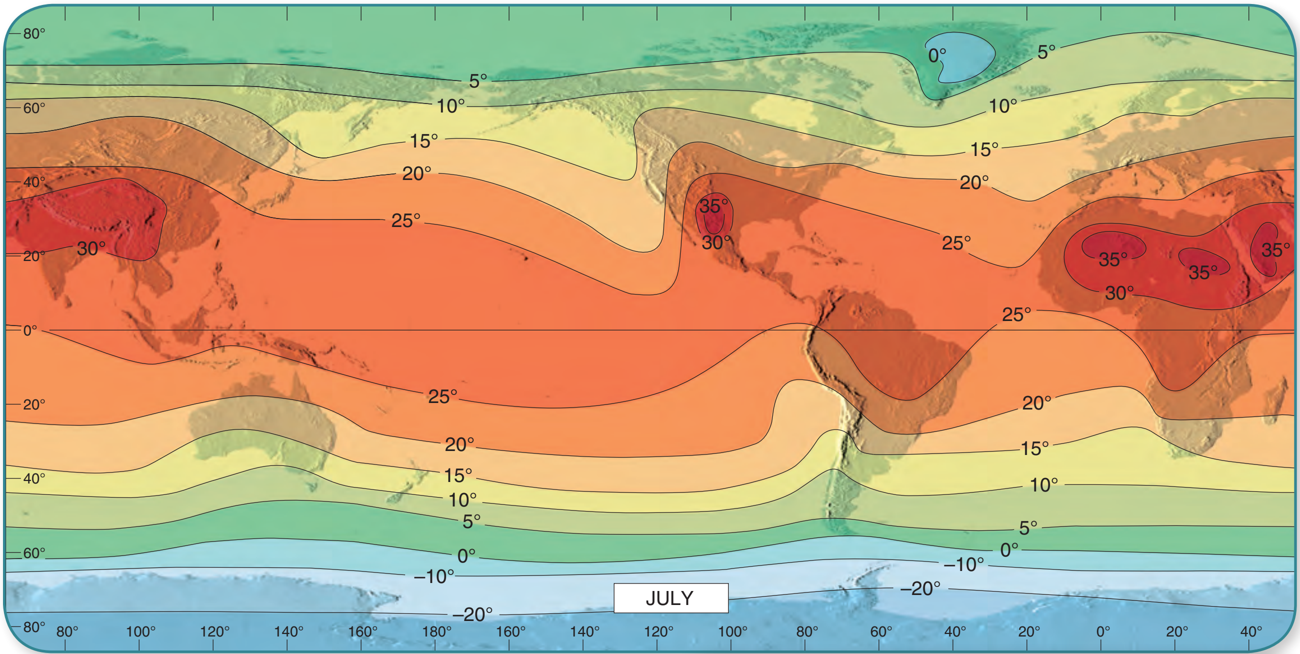


FIGURE 20 **World Isothermal Map**

On this map, you can study global temperature patterns and the effects of the controlling factors of temperature, especially latitude, distribution of land and water, and ocean currents. The isotherms generally trend east and west and show a decrease in temperatures from the tropics toward the poles. This map emphasizes the importance of latitude as a control on incoming solar radiation, which in turn heats Earth's surface and the atmosphere above it.

MAP IT! ACTIVITY

The map in Figure 20 shows the distribution of world mean sea-level temperatures averaged for the month of July.

Interpret Maps Estimate the latitude range for temperatures between 20 and 25 degrees Celsius in the Northern Hemisphere. Approximate to the nearest 5 degrees latitude for each extreme.

Predict Do you expect the color of the temperature band to change near the equator for the month of January? Explain your prediction.

17.3 Assessment

Review Key Concepts

1. What is a temperature control?
2. How do the heating of land and water differ?
3. Why do many clouds reflect a significant amount of sunlight back to space?
4. Why do some coastal cities experience a moderation of temperature from water, while others do not?
5. List four specific controls of atmospheric temperature.

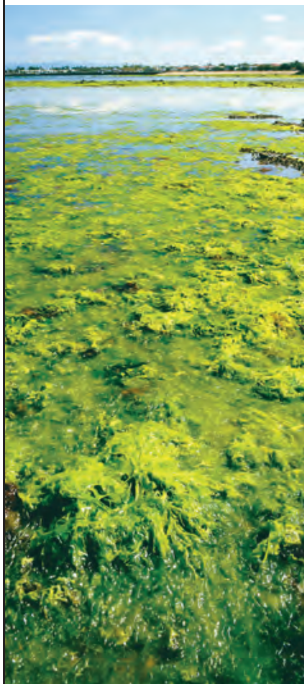
Think Critically

6. **Infer** Look back at the graph in Figure 18. Why do the temperatures of these two cities stay within a limited range throughout the year?

MATH PRACTICE

7. **Calculate** Using the data in Table 1, determine the latitude that shows the greatest variation in annual mean temperature between the Northern and Southern Hemispheres.

How Earth Works



Earth's Atmosphere

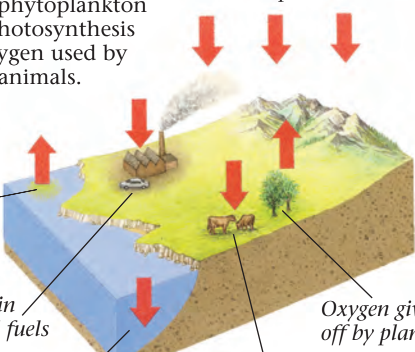
The outermost part of Earth is the atmosphere, a multilayered mixture of gases (such as nitrogen, oxygen, and water vapor) and tiny solid particles. The atmosphere extends at least 1000 km (600 miles) above the solid surface of Earth, but about half of its mass is in the lowest 3.5 miles (5.6 km). The atmosphere's gases support life on Earth. They also protect Earth from the sun's harmful rays.

The layer of the atmosphere closest to land is the **troposphere,** which contains the air that we breathe. Here, temperature and humidity change rapidly, and the air is turbulent, creating weather patterns.

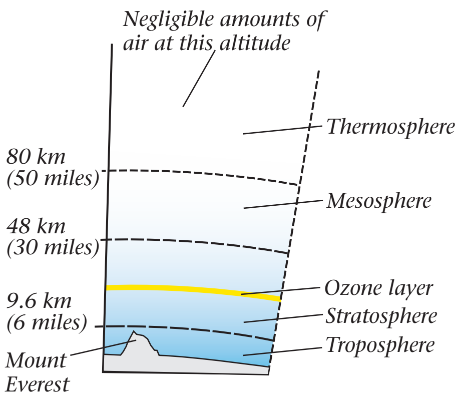
▲ **OXYGEN FROM PHOTOSYNTHESIS**
Oxygen is a relative newcomer in Earth's atmosphere. It has come from plants and phytoplankton that, during **photosynthesis,** use carbon dioxide to make their food, while giving out oxygen. The earliest photosynthesizing organisms, which probably looked like these phytoplankton, evolved about 3.5 billion years ago.

THE ATMOSPHERE FROM SPACE ▶
Viewed from space, Earth looks totally unlike other planets of our solar system. It is partly shrouded in white clouds, which swirl in patterns, sometimes releasing precipitation. **Clouds** are masses of tiny particles of water and dust floating in the atmosphere. A very low cloud is called fog.

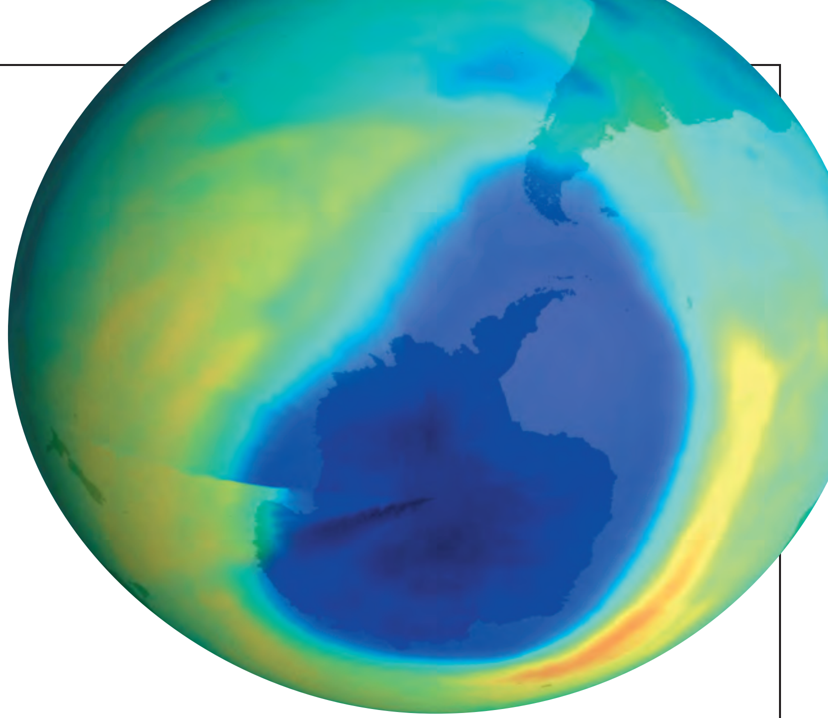
OXYGEN CYCLE ▶
A vast store of oxygen exists in oceans, rocks, and the atmosphere. Oxygen released by phytoplankton and plant photosynthesis balances oxygen used by people and animals.



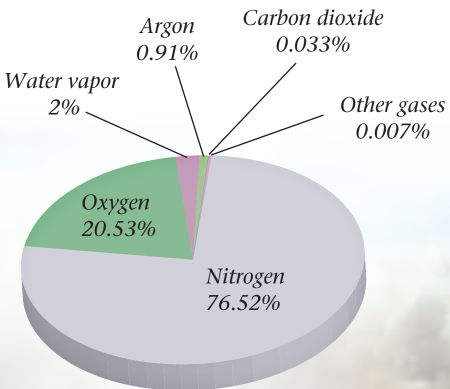
FERTILE LAND ▶
The atmosphere helps life to flourish on Earth. It offers protection from harmful radiation and provides nourishment for both plants and animals. Winds in the troposphere moderate daily and seasonal temperatures by distributing heat around the world.



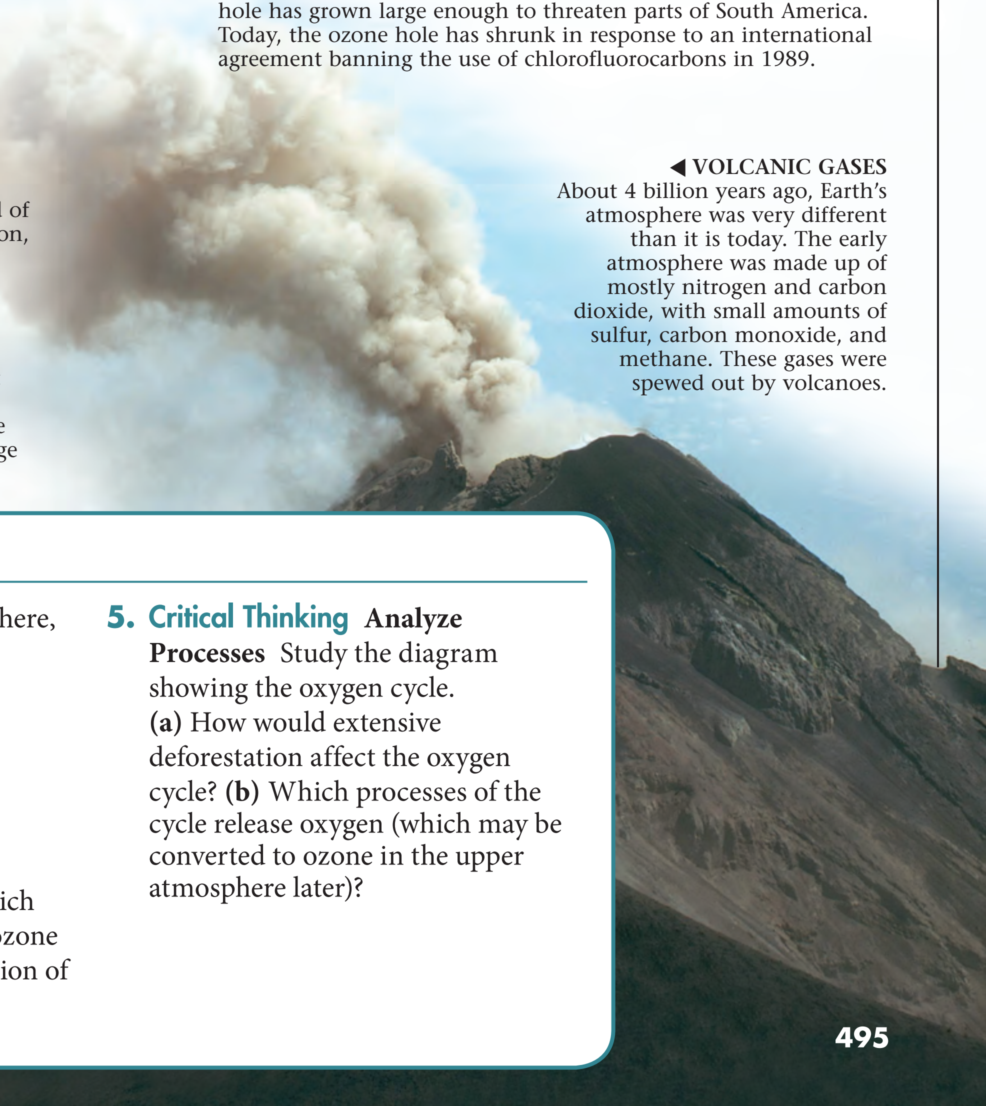
▲ **LAYERS OF ATMOSPHERE**
Earth's atmosphere has several layers. The heights of these layers vary with season and latitude. Weather is confined to the troposphere, and almost all clouds are within this level. In the stratosphere lies the ozone layer that protects life on Earth from harmful UV radiation.



▲ **OZONE HOLE**
The **ozone layer** is a region of ozone gas in the stratosphere that absorbs the sun's harmful ultraviolet rays. The ozone layer is vital for the survival of life on Earth. The thickness of the ozone layer varies naturally, affected by processes such as volcanic eruptions. In the 1980s, a hole in the ozone layer over Antarctica was discovered. Scientists hypothesized that the hole was caused by gases called chlorofluorocarbons (CFCs). CFCs were used at that time as propellants in spray cans, such as hair spray. These gases break down ozone in the stratosphere. As a result, the ozone layer got thinner each winter, and the hole got wider. At times, the ozone hole has grown large enough to threaten parts of South America. Today, the ozone hole has shrunk in response to an international agreement banning the use of chlorofluorocarbons in 1989.



▲ **COMPOSITION OF ATMOSPHERE**
Earth's atmosphere is largely composed of nitrogen and oxygen. Water vapor, argon, and carbon dioxide, as well as many other gases, are also present, though at much lower concentrations. Note that the amount of water vapor in Earth's atmosphere varies significantly with location. Above deserts, there is almost no water vapor present, while above tropical regions, the atmosphere can be nearly 4 percent water vapor. An average value of 2 percent is shown here.



◀ **VOLCANIC GASES**
About 4 billion years ago, Earth's atmosphere was very different than it is today. The early atmosphere was made up of mostly nitrogen and carbon dioxide, with small amounts of sulfur, carbon monoxide, and methane. These gases were spewed out by volcanoes.

Assessment

1. **Key Terms** Define **(a)** troposphere, **(b)** photosynthesis, **(c)** cloud, **(d)** ozone layer.
2. **Physical Processes** How was Earth's atmosphere formed?
3. **Natural Resources** How does carbon dioxide support life?
4. **Geographic Tools** Within which layer of the atmosphere is the ozone layer found? What is the function of the ozone layer?
5. **Critical Thinking** **Analyze Processes** Study the diagram showing the oxygen cycle. **(a)** How would extensive deforestation affect the oxygen cycle? **(b)** Which processes of the cycle release oxygen (which may be converted to ozone in the upper atmosphere later)?

INQUIRY
EXPLORATION LAB

Heating Land and Water

Problem How do the heating of land and water compare?

Materials 2 250-mL beakers, dry sand, tap water, ring stand, light source, 2 flat wooden sticks, 2 thermometers, graph paper, 3 colored pencils

Skills Model, Observe, Measure, Analyze Data

Connect to the Big idea In this lab you will model the difference in the heating of land and water when they are subjected to a source of radiation. You fi st will assemble simple tools. Then you will observe and record temperature data. Finally, you will explain the results of the experiment and how they relate to the moderating influence of water on air temperatures near Earth's surface.

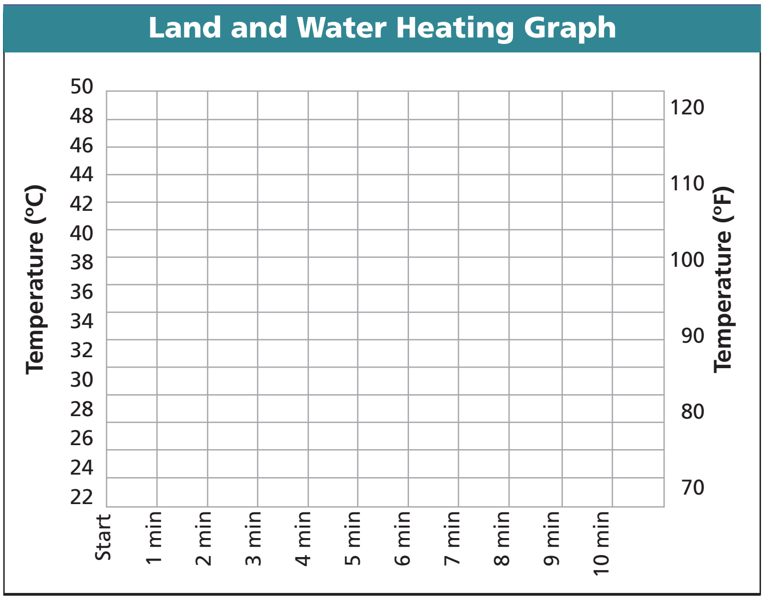
Procedure

Part A: Preparing for the Experiment

1. On a separate sheet of paper or on a computer spreadsheet, copy the data table shown.
2. Pour 200 mL of dry sand into one of the beakers. Pour 200 mL of water into the other beaker.

Land and Water Heating Data Table

	Starting Temperature	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
Water											
Dry sand											
Damp sand											



3. Hang a light source from a ring stand so that it is about 5 inches above the beaker of sand and the beaker of water. The light should be situated so that it is at the same height above both beakers, as shown in the photo.
4. Using the wooden sticks, suspend a thermometer in each beaker. The thermometer bulbs should be just barely below the surfaces of the sand and the water.
5. Record the starting temperatures for both the dry sand and the water in the data table.

Part B: Heating the Beakers

Caution *Do not touch the light source or the beakers without using thermal mitts.*

6. Turn on the light. Observe and record the temperatures in the data table at one-minute intervals for 10 minutes.
7. Turn off he light for several minutes. Dampen the sand with water and record the starting temperature for damp sand. Repeat step 6 for the damp sand.

Analyze and Conclude

1. **Use Tables and Graphs** Use a computer to graph the data you collected on a graph like the one above. Plot the temperatures for the water, dry sand, and damp sand. Use a different color line to connect the points for each material. Include labels for the lines or a key to the graph.
2. **Compare and Contrast** How does the changing temperature differ for dry sand and water when they are exposed to equal amounts of radiation?
3. **Compare and Contrast** How does the changing temperature differ for dry sand and damp sand when they are exposed to equal amounts of radiation?
4. **Apply** Locate Eureka, California, and Lafayette, Indiana, on a map. Infer which city would show the greatest annual temperature range. Explain your answer.
5. **Communicate** Write a lab report explaining your procedures and conclusions for this lab.

ES.1 The student will plan and conduct investigations in which **a.** volume, area, mass, elapsed time, direction, temperature, pressure, distance, density, and changes in elevation/depth are calculated utilizing the most appropriate tools; **c.** scales, diagrams, charts, graphs, tables, imagery, models, and profiles are constructed and interpreted; and **e.** variables are manipulated with repeated trials.

17 Study Guide

Big idea Weather and Climate

17.1 Atmosphere Characteristics

Weather refers to the state of the atmosphere at any given time or place. Weather is constantly changing. Climate is the sum of all statistical weather information that helps describe a place or region.

Water vapor is the source of all clouds and precipitation. Like carbon dioxide, it absorbs heat given off by Earth as well as some solar energy.

If ozone did not filter most UV radiation, Earth would be uninhabitable for many living organisms.

The atmosphere thins as you travel away from Earth, until there are too few gas molecules to detect.

The atmosphere can be divided vertically into four layers based on temperature.

Seasonal changes occur because Earth's position relative to the sun continually changes as it travels along its orbit.

ozone (478)
troposphere (480)
stratosphere (480)
mesosphere (480)
thermosphere (480)
summer solstice (482)
winter solstice (482)
autumnal equinox (482)
spring equinox (482)

17.2 Heating the Atmosphere

Heat is the transfer of energy between two objects resulting from differences in their temperatures. Temperature is a measure of the average kinetic energy of individual particles.

Three mechanisms of heat transfer are conduction, convection, and radiation. Unlike conduction and convection, radiant energy can travel through the vacuum of space.

All objects, at any temperature, emit radiant energy. Hotter objects radiate more total energy per unit area than colder objects do. The hottest radiating bodies produce the shortest wavelengths of maximum radiation. Objects that are good absorbers of radiation are good emitters as well.

Objects can absorb, transmit, scatter, or reflect radiation that strikes them.

heat (483)
temperature (483)
conduction (483)
convection (484)
radiation (485)
reflection (486)
scattering (486)
greenhouse effect (487)

17.3 Temperature Controls

Factors other than latitude that exert a strong influence on temperature include heating of land and water, altitude, geographic position, cloud cover, and ocean currents.

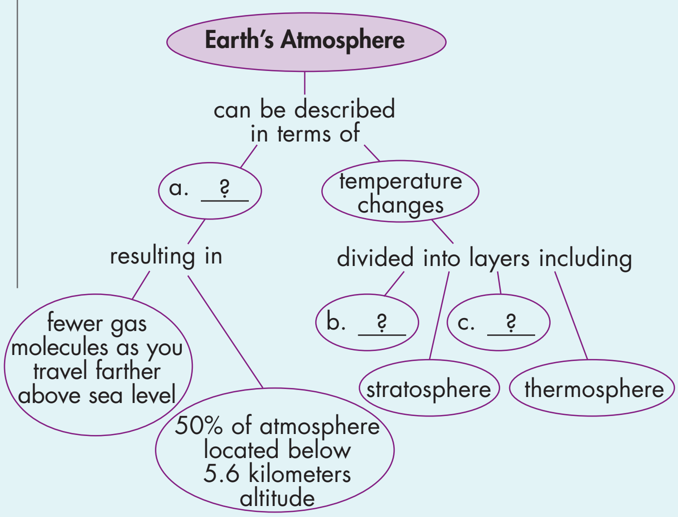
Land heats more rapidly and to higher temperatures than water. Land also cools more rapidly and to lower temperatures than water.

Many clouds have a high albedo, and therefore reflect a significant portion of the sunlight that strikes them back to space.

albedo (492)
isotherm (492)

Think Visually

Concept Map Copy the concept map below onto a sheet of paper. Use information from the chapter to complete the concept map.



17 Assessment

Review Content

Choose the letter that best answers the question or completes the statement.

1. What is a description of atmospheric conditions over a long period of time?
a. climate **c.** precipitation
b. meteorology **d.** weather

2. The bottom layer of the atmosphere in which we live is called the
a. mesosphere. **c.** thermosphere.
b. stratosphere. **d.** troposphere.

3. Which form of radiation has the longest wavelength?
a. blue light **c.** radio waves
b. infrared **d.** ultraviolet

4. This layer of atmosphere contains ozone that filters UV radiation.
a. mesosphere **c.** thermosphere
b. stratosphere **d.** troposphere

5. The average kinetic energy of all the atoms and molecules that make up a substance is referred to as
a. radiation. **c.** temperature.
b. greenhouse effect. **d.** heat.

6. The two principle absorbers of radiation emitted by Earth's surface are carbon dioxide and
a. nitrogen. **c.** ozone.
b. oxygen. **d.** water vapor.

7. On a map showing temperature distributions, what are the lines connecting points of equal temperature?
a. isobars **c.** isotherms
b. isotemps **d.** equigrads

8. Which gas is most abundant in clean, dry air?
a. argon **c.** nitrogen
b. carbon dioxide **d.** oxygen

9. Select the best description of air.
a. It is a compound.
b. It is an element.
c. It is a mixture.
d. It is mainly oxygen and carbon dioxide.

10. Earth's atmosphere is thought to have become enriched in which gas about 2.5 billion years ago?
a. argon **c.** nitrogen
b. carbon dioxide **d.** oxygen

Understand Concepts

11. Why are temperature variations greater over dry land than they are over water?

12. Describe how the ozone in the stratosphere forms.

13. Describe the three types of heat transfer in the atmosphere.

14. In what ways can geographic position be considered a temperature control?

15. Describe the two principle motions of Earth.

16. Explain why Earth's troposphere is mainly heated from the ground up.

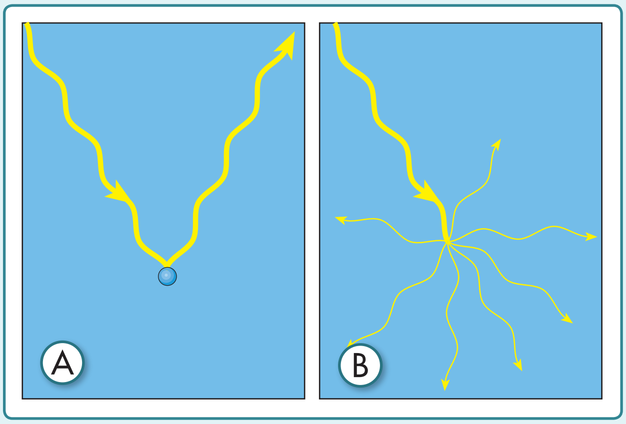
17. Describe the effects of cloud cover on air temperature.

18. Why do temperatures increase in the stratosphere?

19. What causes the position of the noon sun to vary by as much as 47 degrees over a year's time?

Use the figure below to answer Question 20.

20. The illustration below shows two ways that radiation bounces off bjects. Identify the process shown in each diagram. What clues in the illustration helped you identify these processes?



Think Critically

21. Analyze Data Using the data in the table, determine which types of surfaces have the highest average albedos.

Albedo of Various Surfaces

Surface	Percent Reflected
Clouds, stratus	
<150 meters thick	25–63
150–300 meters thick	45–75
300–600 meters thick	59–84
Average of all types and thicknesses	50–55
Concrete	17–27
Crops, green	5–25
Forest, green	5–10
Meadows, green	5–25
Plowed field, moist	14–17
Road, blacktop	5–10
Sand, white	30–60
Snow, fresh-fallen	80–90
Snow, old	45–70
Soil, dark	5–15
Soil, light (or desert)	25–30
Water	8*

*Typical albedo value for a water surface. The albedo of a water surface varies greatly depending upon the angle of the sun.

22. Apply Concepts Determine the date after which the length of daylight gets progressively longer going south from the equator. Use Figure 8 to explain your answer.

23. Infer Give an example of how the Earth system might be affected if Earth's axis were perpendicular to the plane of its orbit instead of being tilted 23.5 degrees.

Math Skills

24. Calculate Assume that the average rate of temperature decrease in the troposphere is 6.5°C/km. Using this rate, determine the air temperature at a height of 2 kilometers if the temperature at sea level were 23°C.

Concepts in Action

25. Infer Yakutsk is located in Siberia at about 60 degrees north latitude. This Russian city has one of the highest average annual temperature ranges in the world: 62.2°C. Explain the reasons for the very high annual temperature range.

26. Predict Speculate on the changes in global temperatures that might occur if Earth had substantially more land area and less ocean area than it does at present. How might such changes influence the biosphere?

27. Apply Concepts Why are carbon dioxide and water vapor such important components in Earth's atmosphere? What would happen to life forms on Earth if these gases were no longer present in the atmosphere?

28. Explain State the relationship between the temperature of a radiating body and the wavelengths of radiation that it emits.

29. Interpret Visuals Refer to Figure 20. What can you determine about temperatures in regions where isotherms are closely spaced, compared with regions where isotherms are farther apart?

30. Writing in Science Write a paragraph that describes two environmental settings where you would expect the albedo of surfaces to be high. Your scenarios can describe any reasonable area on Earth's surface. Be sure to include as much detail as possible in your paragraph.

Performance-Based Assessment

Design an Experiment Design and conduct an experiment that models how variations in color of an object can affect the amount of radiation it absorbs. As a first step, write a clear hypothesis statement. Then plan the materials you will need to design the experiment. Have your teacher approve your plan before you begin.

Virginia SOL Test Prep

Tips for Success

Sometimes all the response choices to a test question look similar. For example, they might have the same prefix or suffix. When all of the answer choices are similar, try answering the question BEFORE looking at the answers. Once you have answered the test item yourself, then look for the answer choice that agrees with your answer. Look for words that are correct words, but do not belong with the others.

The transfer of heat through matter by molecular activity occurs in—

A convection
B conduction
C radiation
D reflection

(Answer: B)

Choose the letter that best answers the question.

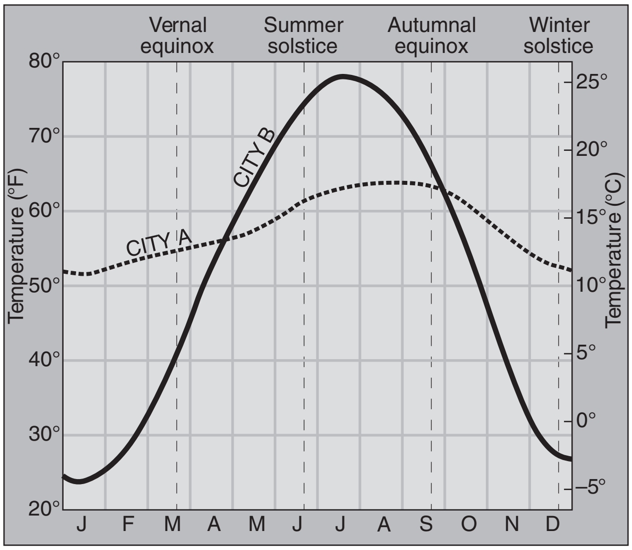
1 Which of these gases plays a more important role in weather processes than the others?
A argon
B carbon dioxide
C nitrogen
D oxygen ES.12.d

2 Practically all clouds and storms occur in this layer of the atmosphere.
F mesosphere
G stratosphere
H thermosphere
J troposphere ES.12.d

3 The primary wavelengths of radiation emitted by Earth's surface are—
A longer than those emitted by the sun
B shorter than those emitted by the sun
C about the same as those emitted by the sun
D about the same as UV radiation ES.12.d

4 Which of the following is true about equinoxes?
F They occur in June and December.
G The sun's vertical rays are striking either the Tropic of Cancer or the Tropic of Capricorn.
H Lengths of daylight and darkness are equal everywhere.
J The length of daylight in the Arctic and Antarctic Circles is 24 hours. ES.3.b

Use the graph below to answer Question 5.



5 Determine the difference in December mean temperatures for cities A and B.
A –2°C
B 10°C
C 12°C
D 14°C ES.3.b

If You Have Trouble With . . .					
Question	1	2	3	4	5
See Lesson	17.1	17.1	17.2	17.1	17.3