

10.1 Global Systems and Solar Energy

While studying different fields of science, you have encountered the term “system” used in a variety of ways. You have probably read about the solar system, the digestive system, and several other systems. The title of this unit is “Energy Flow in Global Systems.” What do scientists mean by the word system? What is meant by “global system” in terms of climate and weather?

Defining Systems

Scientists define a **system** as precisely the object or group of objects that they wish to study. Everything other than the system is called the **surroundings**. This implies that a system has a boundary. An astronomer might study the solar system. A biologist known as a physiologist might choose to study the digestive system. A physicist might study a thermodynamic system. After you have determined what constitutes a particular system, you can design your experiments to fit that system. Researchers can learn a lot about a particular system by observing what enters and leaves it. They make observations on how the matter and energy that interact with the system affects it.

Scientists classify systems according to the interactions of a particular system with its surroundings. The three classes of systems are defined as follows.

- An **open system** allows energy and matter to cross the system’s boundary. An aspen poplar tree, shown in Figure 10.1, is an open system.
- A **closed system** allows only energy but not matter to cross the boundary. Earth is a closed system with the exception of the relatively small amount of matter that enters and leaves the system (see Figure 10.2). This matter includes meteors that burn up in the atmosphere, and meteorites that strike Earth’s surface. This matter also includes spacecraft that leave Earth to probe the solar system and universe.
- An **isolated system** allows neither matter nor energy to flow across the boundary. Since it is so difficult to isolate any system absolutely, some scientists say that the only truly isolated system is the universe.

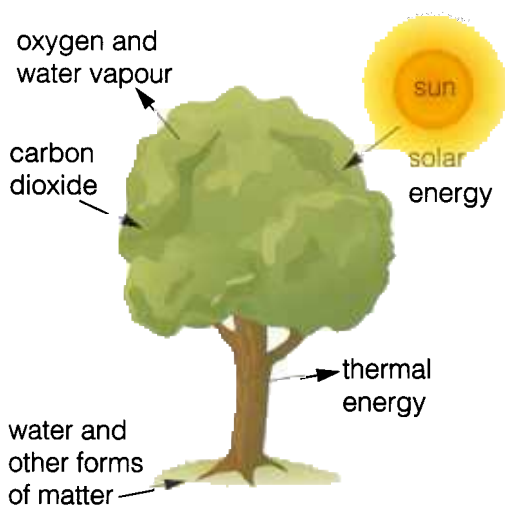


Figure 10.1 An aspen poplar tree is an example of an open system in which matter and energy flow to and from the surrounding soil and air. For example, water, mineral nutrients, and carbon dioxide enter the tree. Water vapour, oxygen and other gases exit the tree. Solar energy enters the tree and thermal energy both enters and exits the system.



Figure 10.2 This view of Earth from space allows you to see the boundary of the system known as Earth — the atmosphere. Solar energy enters the atmosphere, where some of this energy is reflected and some is absorbed. The remaining energy is transmitted to Earth’s surface, where some is reflected and some absorbed. Ultimately all the energy absorbed by the atmosphere and the surface of Earth is radiated back into space.

The Biosphere

The most important global system that you will examine in this chapter is the biosphere. When radiant energy from the Sun reaches Earth, it interacts with just a thin layer of air, land, and water on or near Earth's surface. This layer is called the **biosphere** because *all life on Earth exists in this thin layer*. Scientists often define and use the following terms when discussing the air, land, and water.

- The **atmosphere** (air) is a mixture of nitrogen and oxygen and other gases that extend 800 km above Earth's surface. Most of the atmosphere is concentrated in the lower two layers — the **troposphere** (0 km–12 km) and the **stratosphere** (13 km–50 km).
- The **lithosphere** (land) is Earth's crust that forms land (continental crust) above sea level and at the ocean bottom (oceanic crust), as well as the uppermost part of Earth's mantle. The lithosphere varies in thickness from 100 km to 200 km.

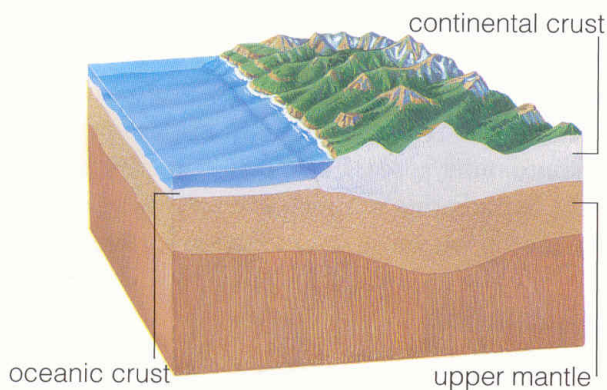


Figure 10.4 Parts of the lithosphere move relative to each other at the rate of a few centimetres per year. Continental drift is the slow movement of the thinner crust on the sea floor. Here new crust is formed and crustal plates meet and move apart.



Figure 10.3 Which two gases make up over 90 percent of Earth's atmosphere?

- The **hydrosphere** (water) is water on or near Earth's surface. The hydrosphere includes water in oceans, rivers, lakes, streams, underground reservoirs, and in the atmosphere. **Clouds** are water droplets found mostly in the troposphere. Clouds reflect much of the incoming solar radiation. Earth's surface is 70 percent water and only 30 percent land. Therefore, the hydrosphere plays an important role in the absorption of sunlight and the distribution of thermal energy. Some scientists define another component within the hydrosphere — the **cryosphere**. The cryosphere consists of water that is temporarily frozen in polar ice caps, snow, permafrost, and glaciers.

As stated above, the land, water, and gases in the air absorb radiant energy from the Sun, warming the biosphere. However, if the biosphere continued to absorb radiant energy without losing any of it, the temperature would continue to increase indefinitely. Life could not exist on Earth. However, conditions in the biosphere remain uniquely suited for life. Why does Earth's average temperature remain fairly constant?

DidYouKnow?

The highest temperature ever recorded on Earth is 56.7°C. This record high occurred on July 10, 1913 in Death Valley, California. The coldest temperature ever recorded was –89.4°C. This record low temperature was recorded on July 21, 1983 at a research station in Vostok, Antarctica.

Earth's Radiation Budget

Imagine that you have \$500 in the bank. If you continue to earn money but spend the same amount that you earn, you will always have \$500 in the bank. This method of budgeting money is similar to the way in which the biosphere budgets thermal energy.

Radiation is the process by which solar energy reaches Earth. **Radiation** is the mechanism of energy transfer in which atoms or molecules emit electromagnetic waves. These waves carry the energy through space and release the energy only when they interact with some form of matter. Solar energy consists of radiation of various wavelengths that are each affected differently as they enter Earth's atmosphere (see Figure 10.5).

Visible light passes through the atmosphere and reaches Earth's surface more or less unchanged. When the visible light reaches Earth's surface, some of it is reflected and some is absorbed. The absorbed sunlight warms the surface. All warm objects emit infrared radiation. Although the atmosphere cannot absorb visible light, it does absorb the infrared radiation from the ground. The atmosphere absorbs and temporarily traps some of this infrared radiation from Earth's surface. The warm air now re-emits the infrared radiation. Some of this radiation leaves the atmosphere but some of it causes additional warming of Earth's surface. Ultimately this infrared radiation from the surface passes through the atmosphere and back into outer space. Earth maintains an energy balance and a temperature balance by radiating as much energy into space as it absorbs from the Sun. This balance is known as the **radiation budget**.

Incoming and Outgoing Radiation

Of the solar energy that enters the atmosphere, 49 percent is absorbed by the land and oceans. Forty-two percent is absorbed, reflected, and scattered by the atmosphere. Nine percent is reflected by Earth's surface. These percentages are annual averages for the entire Earth (see Figure 10.6). Clouds and Earth's surface reflect solar energy back to space. Dust particles and gases such as water vapour scatter sunlight, resulting in a blue sky and reddish orange sky at sunset. Higher

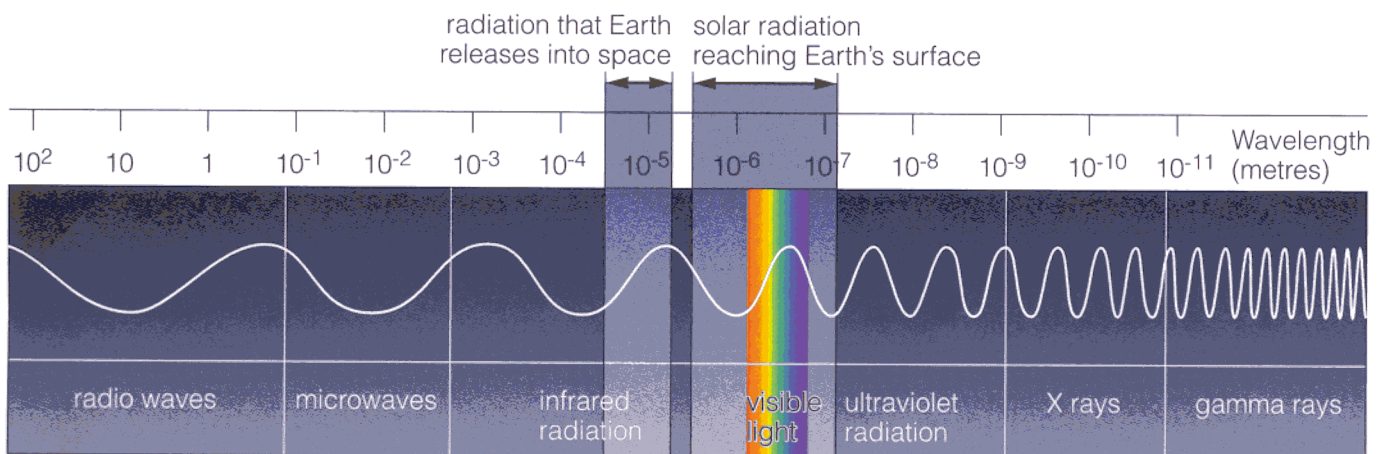


Figure 10.5 Much of the highly energetic, short-wave radiation, such as gamma rays, X rays, and ultraviolet light, is absorbed by the middle to upper regions of the atmosphere. Much of the longer wavelength infrared, microwave, and radio wave radiation is absorbed by carbon dioxide and water vapour in the lower atmosphere.

in the atmosphere where there is less dust and gas to scatter sunlight, the blue sky fades to the black of outer space. Regardless of whether solar energy is absorbed, reflected, or scattered, all of it is eventually radiated to space. The solar radiation budget shows the incoming and outgoing solar radiation. It also indicates how much and where the radiation is absorbed and reflected.

The colour of a surface affects the amount of energy it will absorb or reflect. Dark surfaces absorb energy and lighter surfaces reflect energy. The reflectivity of a surface is known as its **albedo**. A snow-covered field, for example, has a high albedo. It might reflect 70–80 percent of the energy striking it. During summer, the same field growing crops will have a lower albedo. It will reflect only 20 percent or less of the incoming energy.

Word CONNECT

The term “albedo” comes from the Latin word *albus*, meaning white. What other word from the same root indicates white, or lack of pigment in skin and hair?

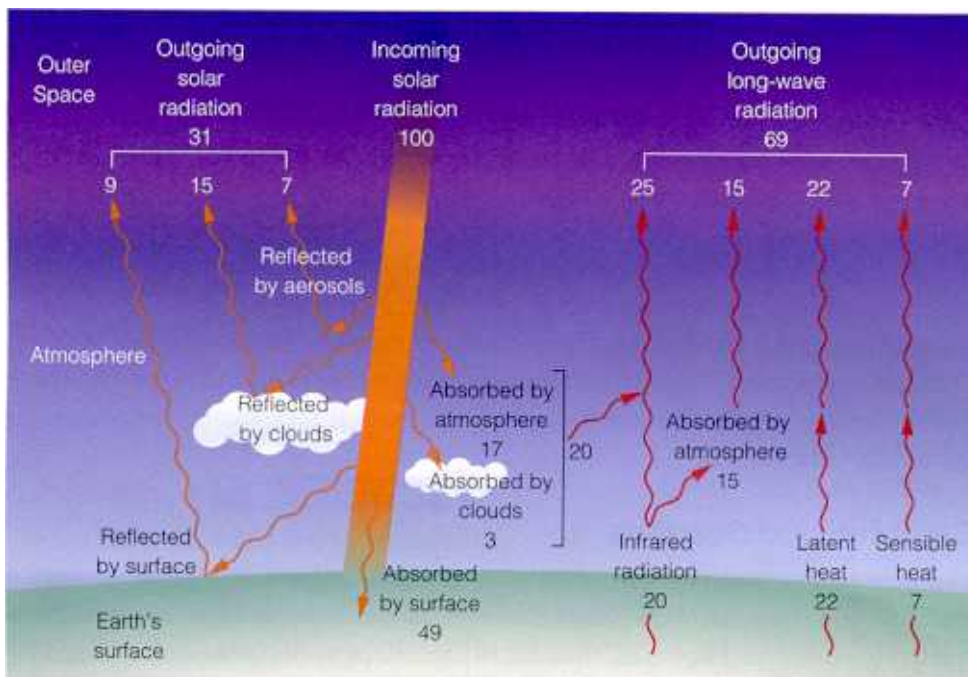


Figure 10.6 The solar radiation budget is based on 100 units of solar energy entering Earth's atmosphere and shows the approximate amounts of energy reflected and absorbed. The red arrows show the infrared energy emitted from Earth. The gaps in the two arrows on the right indicate that the energy leaving Earth's surface and the atmosphere does not happen directly and may contribute to warming of Earth's surface. (Note: Sensible heat is heat that you can “sense” or feel. Latent heat is heat that melts ice or snow, or evaporates water. When the water condenses or freezes, the latent heat is released.)

DidYouKnow?

Do you look forward to skiing, snowboarding, or snow-shoeing in the mountains? Fresh, clean snow may have an albedo greater than 90 percent. This very high albedo, together with the higher elevation and thinner atmosphere in the mountains, makes it extremely important to protect your eyes and skin against both the direct and reflected rays of the Sun, especially the ultraviolet radiation.



Dust, ash, and sulfur dioxide from erupting volcanoes reflect solar energy and prevent it from reaching and warming Earth's surface. Depending on the size of the eruption, dust particles and gases can remain in the atmosphere for two or more years. For example, the 1815 eruption of the volcano Tambora in Indonesia sent 40 billion t of dust high into the atmosphere. As the dust spread around the world, it reflected solar energy and caused the average global temperature to drop 0.7°C. As a result, 1816 became known as the year without summer. By comparison, in 1982, Mount St. Helens in Washington state erupted, releasing 500 million t of dust, about one eightieth the amount of Tambora.

argon 0.93%
carbon
dioxide 0.03%

neon
helium
methane
krypton
xenon
hydrogen
ozone

trace 1%

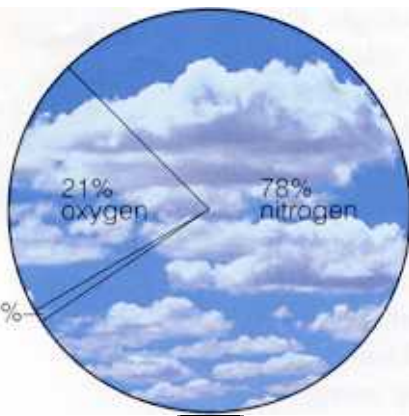


Figure 10.7 Only two gases, nitrogen and oxygen, make up 99 percent of the atmosphere. Water vapour is not included in the graph because of the large variation in amounts present.

DidYouKnow?

The term “greenhouse effect” is useful to describe the warming of the atmosphere. However, there are differences between the warming of the air in an actual greenhouse and what occurs in the atmosphere at Earth’s surface. As the Sun warms the air inside a greenhouse or in a car, the glass prevents the warm air from rising and leaving. Unlike a glass greenhouse, the greenhouse effect does not prevent the physical movement of warm and cooler air.

Keeping in the Heat

Why doesn’t heat just radiate into space at night, cooling off Earth once the Sun sets?

Of the many gases that make up the atmosphere (see Figure 10.7), only a few absorb the infrared radiation released from Earth’s surface. These few are the **greenhouse gases**. These gases include water vapour, carbon dioxide, methane, nitrous oxide (dinitrogen monoxide), ground level (tropospheric) ozone, and the halocarbons such as chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs). Greenhouse gases absorb infrared radiation and transmit it in all directions,

including back to Earth’s surface. This radiation warms the surface and the atmosphere before it is eventually lost to outer space. Thus the greenhouse gases cause the lower atmosphere to retain more heat than would occur if these gases were not present. The retention of heat by the greenhouse gases is known as the **greenhouse effect**.

The average global temperature is about 14°C, which is warm enough to sustain life. Without the greenhouse gases, solar energy would warm Earth only to an average global temperature of –19°C, a difference of 33°C. Without greenhouse gases, Earth would be too cold to support life as we know it.

What might result if the greenhouse effect were enhanced and more infrared radiation were retained by the atmosphere? You will investigate this question further in Chapter 12.

Climates and Seasons

You have been examining the interaction of the biosphere with energy from the Sun. You have discovered how the average temperature of Earth remains relatively constant. However, thus far in the chapter, no mention has been made of climates and seasons. Your own experience tells you that the average temperatures change a great deal from summer to winter. You also know that the average temperatures are quite different in various parts of the world. These characteristics are part of what we call climate. **Climate** is the trend in temperature, atmospheric pressure, humidity, and precipitation over a period of many years. The term **weather** applies to these conditions as they are *at one place and time*. Why does the weather change with the seasons? Why is climate so different from place to place in the world? You will find some answers to these questions when you complete the following activity and investigation.

Word CONNECT

Heat is the transfer of thermal energy. *Infrared radiation* (IR) is emitted by all objects that have a temperature above absolute zero. IR is part of the electromagnetic spectrum and can be transmitted through “empty” space. Therefore, IR radiant heat can heat objects without having to heat the air between them. The molecules in substances that have a temperature above absolute zero are in constant motion. The energy of this motion is called kinetic energy. The higher the temperature, the faster the molecules move and the higher is the kinetic energy. Temperature is a measurement of the average kinetic energy of atoms and molecules.

Find Out **ACTIVITY**



Earth's Curvature

How do latitude (degrees north or south of the equator) and Earth's curvature affect the amount of solar radiation that reaches each square metre of Earth's surface area?

Safety Precautions

- Use care in clamping the flashlight. Ensure that it is securely clamped.

Materials

flashlight with a strong, narrow beam
black construction paper
scissors
tape
ruler or tape measure
support stand
clamp
globe

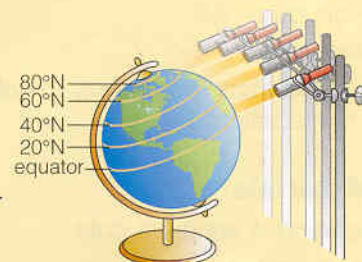
Procedure **Performing and Recording**

1. Prepare a table like this one.

Latitude	Area (cm ²)	Ratio
equator		
20°N		
40°N		
60°N		
80°N		

2. Roll a piece of black paper into a tube. Attach it to the bulb end of the flashlight.
3. Cut out a 1.5 cm square from the middle of another piece of black paper. Attach the paper to the tube, with the square hole positioned over the end of the tube.
4. Attach the flashlight to a support stand with a large clamp. Position the flashlight so the beam of light is perpendicular to the globe's equator and the edge of the beam is sharp. The opening of the tube will be about 3–5 cm away from the globe.

5. Position the flashlight so that the bottom edge of the beam is on the equator. Measure the bottom edge and one side of the square where the light is brightest. Calculate the area in square centimetres.
6. Record the distance between the edge of the tube and the globe's surface.
7. Move the flashlight to the latitudes 20°N, 40°N, 60°N, and 80°N so that the bottom edge of the beam is on the line of these latitudes. With each movement keep the front edge of the tube the same relative distance from the globe's surface as it was at the equator. Keep the beam perpendicular to the equator. Measure the lit region and calculate the area in square centimetres.
8. In the third column record the ratio of the area at the equator to the areas of the other latitudes (e.g., ratio = lit area in cm² at the equator ÷ lit area in cm² at 20°N). Record the ratio to two decimal places.



What Did You Find Out? **Analyzing and Interpreting**

1. About 660 J/m² of solar energy reaches Earth's surface each second when the Sun is directly overhead, such as when it is perpendicular to the equator. Calculate how much energy would be received at each of the latitudes based on your ratios (660 J/m² × the ratio).
2. Write a brief paragraph describing how Earth's curvature affects the amount of energy absorbed per square metre of Earth's surface.

Tilt and Turn

Earth rotates on its axis every 24 h, producing day and night. Earth's annual revolution around the Sun and the 23.5° tilt of its axis produce the variation in the length of day and night and the changes in seasonal heating. In this investigation, you will use Co-ordinated Universal Time (UTC) as a reference time. UTC is the time at zero longitude, the imaginary line from the North Pole to the South Pole, that passes through Greenwich, England.

Question

How do two movements of Earth and the tilt of its axis cause the seasons and hours of daylight?

Safety Precaution

- Ensure that the flashlight is securely clamped.

Apparatus

globe
strong flashlight
protractor
metre stick
support stand and clamp to hold the flashlight

Materials

removable adhesive dots
masking tape

Procedure

Part 1

- 1 On the globe, find the meridian of longitude that passes near your community.



- 2 Use adhesive dots, to label the following points on the meridian of longitude near your community that you identified in step 1.
 - (a) 60°N latitude
 - (b) your community
 - (c) 30°N latitude
 - (d) equator
 - (e) 30°S latitude
 - (f) 60°S latitude
 - (g) North Pole
 - (h) South Pole
- 3 Assign one or more dots to each person in your group. Each person will record information about the location represented by the dots when you start to collect data.
- 4 Earth rotates 360° in 24 h. Determine the number of degrees it rotates in 1 h.
- 5 Put the globe on a table, and set up the flashlight about 2 or 3 m away. Position the flashlight so that it shines directly on the centre of the globe. Position the globe so that the North Pole is directed away from the flashlight.
- 6 Rotate the globe so that the "Sun" (flashlight) shines directly on the International Date Line (180°W or E longitude). The prime meridian (0° longitude) should be in the centre of the dark area. Record the reference time as midnight UTC. Record whether your dot is in daylight, dark, dawn, or dusk.
- 7 Tape a small strip of masking tape (about 2 mm wide) on the exact top and bottom of the globe. These are the locations that are just between darkness and light.
- 8 Estimate the point at the very centre of the globe, where the "sunlight" is striking perpendicular to the surface of the globe. Place a small strip of masking tape at this point.

- 9 Rotate the globe to the East (counterclockwise) the equivalent of 1 h (the number of degrees you determined in step 4) so that it is 1:00 A.M. UTC. **Record** the reference time. Also **record** whether your dot is in daylight, dark, dawn, or dusk.
- 10 Continue to turn the globe the equivalent of 1 h, until you have completed one full “day.” **Record** the data for each position, and tape strips of masking tape as directed in steps 7 and 8.
- 11 Turn the base of the globe 90°. Repeat steps 5–9, but do not tape the strips of masking tape to the top, centre, or bottom of the globe.
- 12 Re-orient the globe so that the North Pole is slanting directly toward the “Sun.” Repeat steps 5–9, including taping the strips of masking tape.

Part 2

- 1 Make three tables (one for each orientation of the globe) as seen below.
- 2 Put all of the data that your group collected in the tables. Give each table a title. Each member of your group should make his or her own copy of the tables.
- 3 Decide what season of the year, in the Northern Hemisphere, is simulated by each orientation of the globe. (Each orientation represents the first day of a season.) For each orientation, determine the day length at each location represented by a dot. **Record** the latitude of each location.

- 4** Use the values you determined in Step 3 to plot three graphs, one for each orientation of the globe. Put “Day length” on the vertical axis and “Latitude” on the horizontal axis. For units on the horizontal axis, start with 90°N, go down to 0° for the equator, and then continue to 90°S. Plot a point for each location (dot) on the globe. Name each graph “First Day of _____,” and fill in the season(s).

Global Position: N pole away from the Sun		
Location (Long. and Lat.) at dot	UTC time	Condition at dot
	00:00	(light or dark)
	01:00	
	02:00	
	...	...
	24:00	

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Analyze

1. Which regions on Earth have the longest and shortest days? Explain.
2. Do the regions that have the longest day also have the warmest summers? Explain.
3. Which regions have the least variation in day length? Describe the climate in these regions.
5. The strips of masking tape that you taped at the top, centre, and bottom of the globe form circles. These circles separate the globe into five regions, or zones. Describe the characteristics of day length and angle of the Sun that make each zone different from the other zones.

Conclude and Apply

4. Which regions do you think have the greatest temperature differences between winter and summer? Explain your reasons for your choices.

Extend Your Knowledge

6. Imagine that Earth's axis has no tilt. Describe how this orientation of Earth's axis would affect day length and seasonal changes at several of the locations you investigated.

DidYouKnow?

Earth's orbit around the Sun is slightly elliptical. Earth is closest to the Sun on January 3 (about 147 million km) and farthest from the Sun on July 4 (about 152 million km).

Earth's Tilted Axis

In the previous activity and investigation you learned that two motions and the tilt of Earth's axis, together with the curvature of Earth's surface, result in different amounts of solar energy absorbed. The 24 h rotation of Earth on its axis results in warming during the day and cooling during the night. The tilt of Earth's axis is called its **angle of inclination**. This angle is the angle of the equator with respect to the plane of Earth's orbit around the Sun. Throughout Earth's year-long revolution around the Sun, the angle of inclination determines the length of day and night at different latitudes. At the equator, day and night are each 12 h long throughout the year. The mid- to higher latitudes have longer summer days and longer winter nights. The very high latitudes have the longest summer days and the longest winter nights.

At the North and South Pole, Earth's axis is tilted towards the Sun for about 182 days or about half a year. It is tilted away from the Sun for the other 182 days. When the axis is tilted towards the Sun in the North during spring and summer, it is tilted away from the Sun in the South. Conversely, when the axis is tilted away from the Sun in the North during fall and winter, it is tilted towards from the Sun in the South.

At the North Pole the Sun is fully above horizon on March 20 and can be seen until September 24. That's about 189 days with 24 hours of daylight. Then on September 24 the Sun sets and is below the horizon for 176 days of darkness. The reverse of darkness and daylight dates occur at the South Pole. Why are the days of daylight and darkness not equal?

The seasons have an unequal number of days because Earth's orbit is slightly elliptical, or oval shaped. The Sun is not exactly at the centre of the orbit. Earth moves faster when it is close to the Sun than when it is farther away. As a result, the seasons that occur when Earth is close to the sun pass more quickly. Earth is closest to the Sun in January and farthest away in July.

Therefore, summer is longer than winter in the northern hemisphere. In the southern hemisphere winter is longer than the summer.

If the axis was not tilted, the Sun would shine directly over the equator. Then the amount of solar energy received by different latitudes would remain the same throughout the year. However, because the axis is tilted, the Northern Hemisphere faces the Sun from about March 20 to September 23, resulting in spring and summer (see Figure 10.8). As the Earth continues to revolve around the Sun from September 23 through March 20, the Northern Hemisphere faces away from the Sun, resulting in fall and winter. What do you think happens in the Southern Hemisphere?

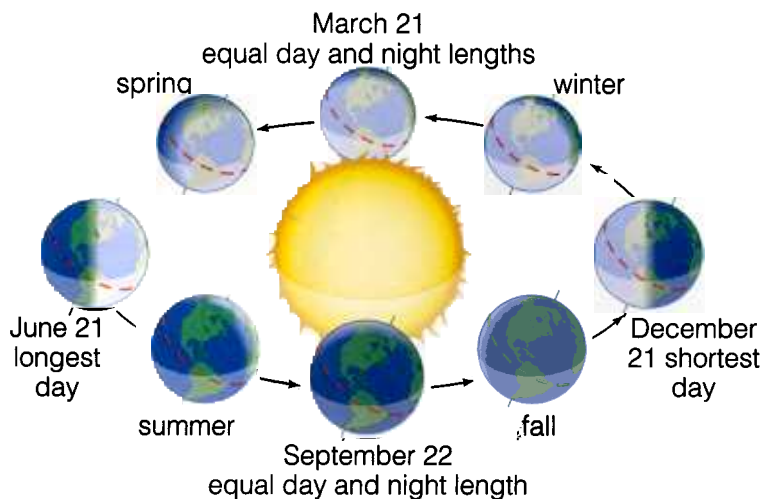


Figure 10.8 The dates and time of the shortest day and longest day may vary by several hours from year to year. Earth spins on its axis like a toy top, and since Earth is not perfectly spherical (it “bulges” at the equator), the axis “wobbles” as it spins. This slight variation in Earth’s axis produces the differences in dates and times.

Warming of Earth Is Unequal

Analyze the conditions when the North Pole is tilted towards the Sun. The Sun’s rays are perpendicular to a line in the Northern Hemisphere. Therefore, it is summer in the Northern Hemisphere. Nevertheless, Earth’s curvature causes solar energy to be distributed unequally. As you go toward the North Pole, the Sun’s rays become more and more slanted relative to Earth’s surface (see Figure 10.9). Solar radiation is spread out over a larger area. Consequently, a smaller amount of solar energy is absorbed by each square metre of surface area. Although day length is 24 h at the North Pole, it is not warm because the solar energy is spread over a very large area. In addition, the solar rays pass through much more atmosphere near the poles and less energy reaches the surface.

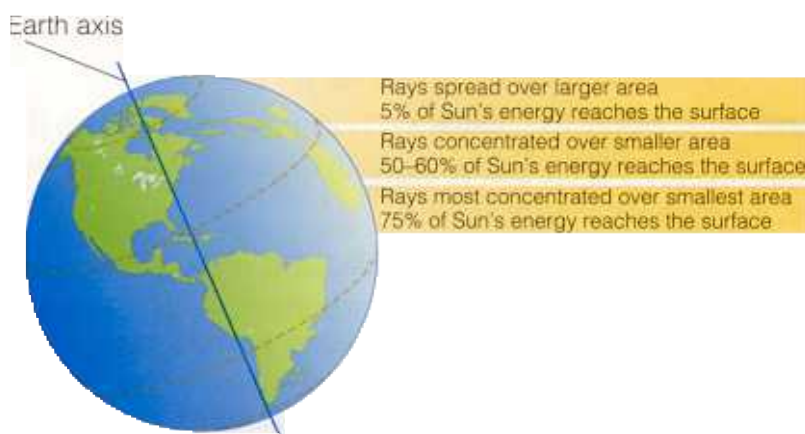


Figure 10.9 Warming of Earth is unequal because of its shape and axis.

Geographers identify three major climate regions, or zones. They are named according to their general climates: *polar*, *temperate*, and *tropical*. Latitudinal lines on maps mark out these climate zones. These lines are called the Arctic Circle, the Tropic of Cancer, the Tropic of Capricorn, and the Antarctic Circle (see Figure 10.10, on the next page).

Word CONNECT

Look up the meaning of the terms “solstice,” “equinox,” “autumnal,” and “vernal” in a dictionary or on the Internet. What days do these terms describe? How do the days vary from the Northern to the Southern Hemisphere?

DidYouKnow?

The timing of the seasons is just the opposite for the Southern Hemisphere compared to the Northern Hemisphere. When it is summer in the Northern Hemisphere, it is winter in the Southern Hemisphere.

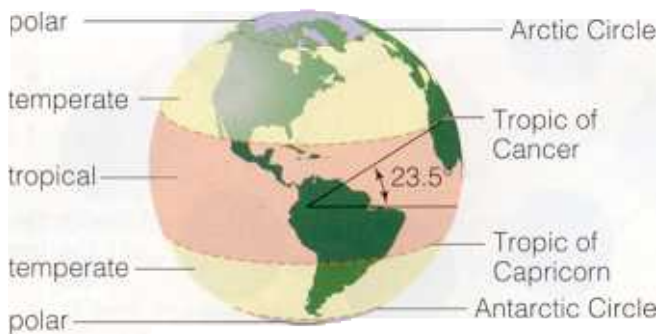


Figure 10.10 Climate zones

The Sun's rays are perpendicular to Earth's surface at some location in the tropical zone throughout the entire year. Therefore, the average temperatures in this zone are generally warmer than those in the other zones.

The Sun's rays are never perpendicular to Earth's surface in the temperate zones. The temperature and weather conditions are quite variable. There is usually a significant difference in the weather during the summer and the winter.

The polar zones have 24 h of darkness during parts of the winter and 24 h of sunlight during parts of the summer. The 24 h of sunlight, however, do not cause significant warming. This is because the Sun's rays make such a small angle with Earth's surface that the energy is spread over a very large area.

Section 10.1 Summary

Solar radiation is absorbed, reflected and transmitted by the biosphere. The biosphere is the thin layer of air, land, and water where life exists. The rotation of Earth on its axis produces day and night. Solar energy warms Earth's surface and the surface warms the atmosphere during the day. At night some cooling occurs, but the greenhouse gases in the atmosphere retain much of the thermal energy.

Earth's average temperature remains relatively constant because Earth radiates the same amount of energy as it receives. The amount of solar energy absorbed by each square metre of Earth's surface is influenced by: (1) Earth's revolution around the Sun, (2) the tilt of Earth's axis relative to the Sun, and (3) Earth's spherical shape.

Check Your Understanding

1. How do open and closed systems differ?
2. Describe three examples of the flow of energy or matter among the lithosphere, hydrosphere, and atmosphere.
3. If the solar rays are perpendicular to a line that is 10° south of the equator, what will be the season in the Northern Hemisphere? Describe the orientation of Earth relative to the Sun when it is winter in the Northern Hemisphere.
4. **Apply** Certain places on Earth are sometimes called "the land of the midnight Sun." Where are these places? How do they earn this name?
5. How does the angle between Earth's axis and the plane of its revolution around the Sun affect the seasons?
6. Why is only about 50 percent of the solar energy that reaches the outer atmosphere absorbed by Earth's surface?
7. How does Earth maintain its relatively constant average temperature?