26. Insolation and the Seasons

Objectives

Determine the effect the angle of the sun has on the temperature of a given surface. Through this investigation, students:

- ♦ Define the term insolation.
- ♦ Deduce how the earth's tilt affects seasonal temperature variations.

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Constructing a solar energy collection panel
- ♦ Going outside and aligning the solar energy collection panel to receive sun rays at three different angles (90°, 60°, and 30°).
- ♦ Measuring the temperature of the solar energy collection panel for five minutes at each of the three different angles
- ♦ Comparing the change in temperature to the angle of insolation.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	75 minutes

Materials and Equipment

For each student or group:

- ♦ Mobile data collection system
- ♦ Fast response temperature sensor
- ♦ Base and support rod
- ♦ Three-finger clamp
- ♦ Protractor
- ♦ Scissors
- ♦ Cardboard, 15 × 15 cm
- ♦ Black construction paper, 15 × 15 cm
- ♦ Drinking straw
- ♦ Tape
- ♦ Glue
- ♦ Sunlight

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Seasons
- Planetary elliptical revolution
- Energy
- Temperature

Related Labs in this Guide

Labs conceptually related to this one include:

- Temperature versus Heat
- Radiation Energy Transfer
- Specific Heat of Sand versus Water

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Showing and hiding data runs in a graph �(7.1.7)
- Viewing statistics of data �(9.4)
- Saving your experiment �(11.1)

Background

Insolation

Insolation is the intensity of *in*coming *sol*ar radi*ation* that strikes a given surface on Earth at a given time. This incoming solar energy is by far the most important factor influencing climate on Earth. Equatorial regions on Earth are hot because they receive intense solar radiation. Polar regions are cold because they receive less solar radiation. In addition to extreme climate differences, seasonal temperature variations can also be explained by changes in insolation. What causes these variations in the solar radiation received at different times and locations on Earth?

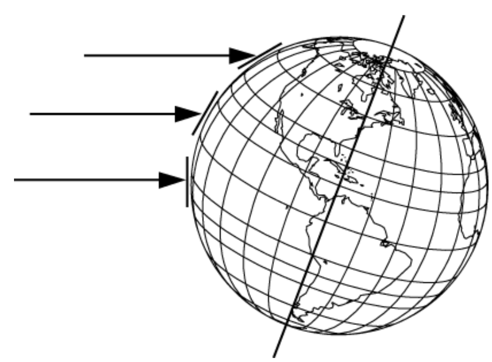
Earth's elliptical orbit around the Sun, Earth's rotation on its axis, and the tilt of Earth's axis all affect the intensity of solar radiation striking the Earth. The distance of Earth from the Sun varies as the Earth revolves around the Sun. The intensity of solar radiation is strongest when Earth is closest to the Sun (147 million kilometers). This position is called the perihelion and occurs around January 4th each year. The intensity of solar radiation is the weakest when Earth is farthest from the Sun (152 million kilometers). This position is called the aphelion and occurs around July 4th each year.

The change in solar intensity due to the distance of the Earth from the Sun is very small because the distance from the Earth to the Sun varies by such a small amount (5 million kilometers). Greater differences in solar intensity can be explained by Earth's tilt as it revolves around the Sun.

Angle of insolation and the seasons

The Earth spins daily around its axis (axis of rotation), which is tilted to approximately 23.5 degrees relative to its orbit around the sun. The rotation of Earth causes night and day while the tilt of the Earth is the primary cause of our seasons. Earth's tilt causes seasonal temperature variations because the solar radiation strikes Earth's surface at different angles. In this activity the students will investigate how the angle of insolation affects the temperature on a given surface.

The angle of insolation changes throughout the year because Earth's tilt stays the same as Earth orbits the Sun. When the Earth is near its perihelion, it is winter in the Northern Hemisphere and summer in the Southern Hemisphere. This is because the tilt of the Earth causes the Southern Hemisphere to receive direct (90°) solar radiation while the solar radiation that reaches the Northern Hemisphere is less intense because it strikes at an angle less than 90°. This causes the Northern Hemisphere to be colder and have shorter days while the Southern Hemisphere is warmer and has longer days. These seasonal differences are due to the angle of insolation.



The seasons are marked by four days in Earth's orbit around the Sun. In the Northern Hemisphere the summer solstice marks the first day of summer (June 21 or 22) and the winter solstice marks the first day of winter (December 21 or 22). Halfway between these dates are the equinoxes. Equinoxes occur when the solar radiation directly hits the equator and creates days and nights of equal length. In the Northern Hemisphere the autumn equinox occurs on September 22 or 23 and the spring equinox occurs on March 21 or 22. In the Southern Hemisphere all the dates are the same, but the seasons are reversed.

Pre-Lab Discussion and Activity

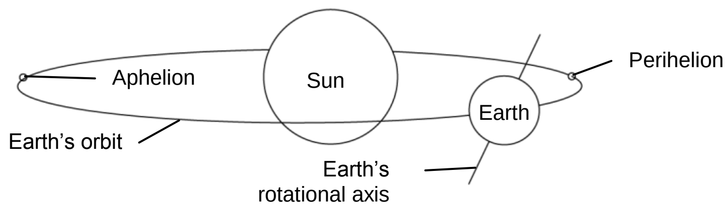
Materials and Equipment for Pre-lab Activities:

- Globe
- Spherical object to represent the sun (basketball)
- Graph paper
- Flashlight

The Earth and Its Seasons

Ask your students to consider why temperatures tend to be cooler in the winter and warmer in the summer. Explain that the earth is physically closer to the sun in January and farther from the sun in July. Point out that the tilt of the axis of rotation means that the Northern Hemisphere is tilted toward the sun during summer and that it is tilted away from the sun during winter.

Which factor—distance from the sun or tilt of the earth relative to the sun would seem to be responsible for warm temperatures in the summertime?



Use a globe and another spherical object, such as a basketball (sun) to model and demonstrate the orbit of the earth around the sun.

1. Make sure the globe is tilted to about 23.5°. Place the basketball in the middle of a large table to model the sun. Put the globe in its perihelion position at the December solstice (closest to the sun with the North Pole tilted away from it). Point out that now the North Pole is pointed towards the sun.

What time of the year is it?

December solstice, December 20 or 21, the shortest day of the year in the Northern Hemisphere and the longest day of the year in the Southern Hemisphere, the beginning of winter in the Northern Hemisphere, the beginning of summer in the Southern Hemisphere.

2. Model the orbit of the earth around the sun as follows. Move the globe in a 90° clockwise arc around the basketball. Make sure the tilt and direction of the axis stays constant. Point out that now the North and South Poles are the same distance from the sun.

What time of the year is it?

March equinox, March 20 or 21, the day when there are 12 hours of daylight and 12 hours of night in both the Northern and Southern Hemispheres, the beginning of spring in the Northern Hemisphere, the beginning of fall in the Southern Hemisphere.

3. **Move the globe in another 90° arc around the sun to the aphelion position at the June solstice (furthest from the sun, with the North Pole tilted towards it). Make sure the tilt and direction of the axis stays constant. Point out that now the North Pole is pointed towards the sun.**

What time of the year is it?

June equinox, June 20 or 21, the longest day of the year in the Northern Hemisphere and the shortest day of the year in the Southern Hemisphere, the beginning of summer in the Northern Hemisphere, the beginning of winter in the Southern Hemisphere.

4. **Move the globe in another 90° arc around the basketball, making sure that the tilt and direction of the axis stays constant. Point out the equivalent distance from the sun of the North and South Poles.**

What time of the year is it?

September equinox, September 22 or 23, the day when there are 12 hours of daylight and 12 hours of night in both the Northern and Southern Hemispheres, the beginning of fall in the Northern Hemisphere, the beginning of spring in the Southern Hemisphere.

5. **When do the warmest temperatures in the summer and the coldest temperatures in the winter usually occur?**

During the next few months after the solstices.

6. **Why do the warmest temperatures in the summer and the coldest temperatures in the winter usually occur after the summer and winter solstices?**

Although the greatest amount of insolation occurs at the summer solstice, the earth absorbs much of this energy, which is then radiated it back into the atmosphere during the next two or three months. The cumulative effect of both the sun's energy and the heat energy radiating from the earth in the months after the summer solstice result in warmer temperatures after the date of the summer solstice.

Conversely, the least amount of insolation occurs at the winter solstice, but because the earth retains heat energy, much of which is subsequently radiated to the trophosphere, it stays warmer, with the coldest surface temperatures occurring during the next two or three months as the radiated heat dissipates.

Angles of Light and Light Intensity

Engage the students in a series of predictions about how the shape of a beam of light changes when the light is shined at different angles. Tape a sheet of graph paper to the board and shine a light at it from a 90 degree angle and then again from a 45 degree angle. Analyze and discuss the results. Conclude the discussion by shining the flashlight on the globe at different angles and having the students suggest how the angle of sunlight affects the temperature on different regions on Earth.

7. **What shape will this flashlight's beam have when it hits the graph paper at a 90 degree angle?**

Answers will vary, but the light beam will be circular.

8. **What shape will this flashlight's beam have when it hits the graph paper from a 45 degree angle?**

Answers will vary, but the light beam will be oblong (egg-shaped).

9. Will the beam of light take up the same area when it is pointed at a 90 degree angle and a 45 degree angle?

Answers will vary, but the light striking straight on will take up a smaller area than the light shined at a 45 degree angle.

10. How do the results compare to our prediction?

Answers will vary based on what the students predictions were, but the beam of light shined at 90 degrees will be circular shaped and take up less area. The beam of light shined at a 45 degree angle will take up more space and be oblong in shape.

11. Does the amount of light coming out of the flashlight change based on the angle the light is held at?

No, the same amount of light is released.

12. How does the intensity of light in the beam compare at 90 degrees versus 45 degrees? Why?

The intensity of light is stronger at 90 degrees than at 45 degrees. The same amount of light is in each beam, but the beam of light is spread out over more space and is therefore less intense when the light is shined at a 45 degree angle.

13. Does the angle that light hits Earth's surface affect the temperature of that region on Earth? Explain.

Students should be able to observe the same characteristic change from a circle to an ellipse on the globe. The goal of the experiment is to address this question.

Lab Preparation

Although this lab activity requires no specific lab preparation, allow 10 minutes to gather the equipment needed to conduct the lab.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Do not look directly at the sun.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

4	2	1	3	5
Remove the solar panel to a shady location to allow it to cool and then repeat the experiment at 30°, and 60°.	Go outside. Set up the solar panel so it is perpendicular (90°) to the sun's incoming rays.	Construct a solar energy collection panel.	Measure the temperature while exposing the apparatus to the sunlight for 5 minutes.	Determine the change in temperature achieved in each of the 3 data runs and compare the results.

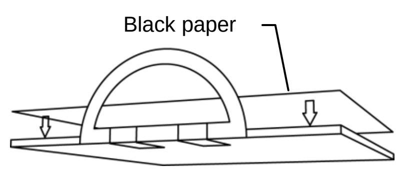
Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Set Up

1. ☐ Make a solar energy collection panel as follows:



a. Glue a piece of black construction paper to the surface of the cardboard.

b. Tape the protractor to it so it is perpendicular to the surface of the cardboard.

2. ☐ Tape the straw to the protractor so that it is perpendicular (90°) to the cardboard and the end of the straw is about 0.5 cm from the surface of the cardboard.

3. ☐ Tape the tip of the temperature sensor to the center of the solar energy collection panel.

4. ☐ You will be aligning your solar energy collection panel so that the sun rays strike it at 90°, 60°, and 30°. At each angle of insolation you will collect temperature data for 5 minutes. Will the angle of insolation affect its temperature after 5 minutes? Why?

The temperature of the solar energy collection panel will increase at all three angles because the black paper absorbs the sun rays. The change in temperature will increase as the angle of insolation increases because the incoming solar radiation is more intense. Therefore the solar energy collection panel at 90° will have the greatest change in temperature.

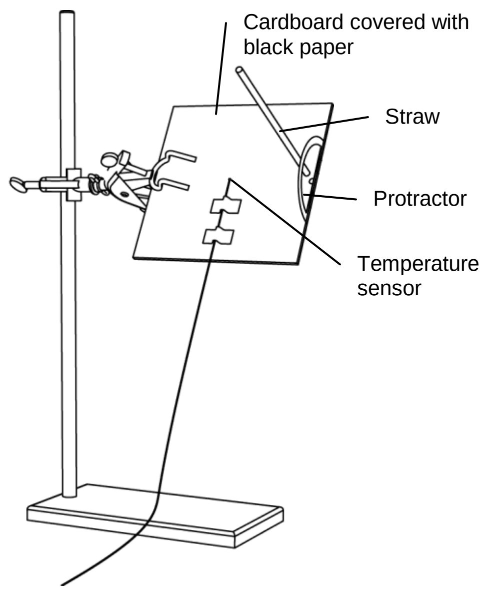
5. ☐ Why did you cover the surface of the cardboard with black paper?

The black paper absorbs more of the light energy than the plain cardboard. This energy is then radiated, so the temperature sensor can better detect differences in the amount of energy that has been absorbed at the various angles of insolation.

6. ☐ Take your solar energy collection panel with the temperature sensor attached, your data collection system, a three-finger clamp, and a base and support rod outside and find a sunny location that is sheltered from the wind.

CAUTION: Do not look directly at the sun when performing the next step.

7. ☐ Use the three-finger clamp and the base and support rod to position the solar energy collection panel so it is perpendicular (90°) to the sun and the straw is pointing at the sun. When the solar energy collection panel is perpendicular to the sun, the shadow cast by the straw will hardly be visible (just a small circle) and a focused spot of light will emerge through the end of the straw.



8. ☐ Start a new experiment on your data collection system. �(1.2)

9. ☐ Connect the temperature sensor to the data collection system. �(2.1)

10. ☐ Display Temperature on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

Collect Data

11. ☐ Start data recording �(6.2)

12. ☐ Adjust the scale of the axes as necessary to see any temperature changes taking place. �(7.1.2)

13. ☐ Record data for 5 minutes.

14. ☐ Write your data run number here: __________

15. ☐ Stop data recording. �(6.2)

16. ☐ Remove the solar energy collection panel and take it to a shaded location to cool completely.

17. ☐ Remove the straw and tape it to the protractor at 60° from the surface of the solar collection panel,

18. ☐ The solar energy collection panel represents a given piece of Earth's surface. You are physically changing the angle of the solar energy collection panel to adjust the angle of insolation. What causes a given area of Earth's surface to receive a different angle of solar radiation?

A given area of Earth's surface will receive a different level of solar radiation at different times during the day and at different times of year (seasonal variation).

19. ☐ Fan the solar energy collection panel to increase the rate of cooling. When its temperature returns to approximately its original temperature, secure it to the base and support rod using the three-finger clamp.

20. ☐ Align the solar panel as before by watching the shadow cast by the straw until it is just a small circle and the focused sport of light can be seen through the straw.

CAUTION: Do not look directly at the sun.

21. ☐ Collect temperature data for five minutes. Follow the steps given above as needed.

22. ☐ Write your data run number here: __________

23. ☐ Remove the solar panel and take it to a shaded location to allow it cool down and to adjust the straw so that it is positioned at the 30° mark from the surface of the solar collection panel.

24. ☐ Secure the solar energy collection panel to the base and support rod and align it as you have done previously.

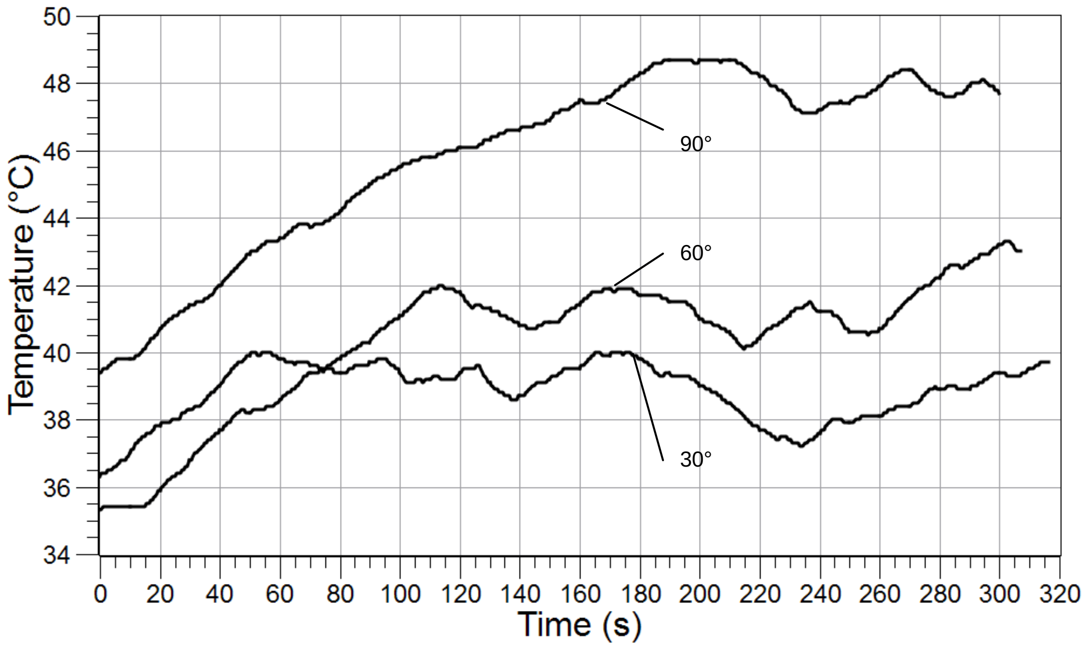
25. ☐ Collect temperature data for five minutes. Follow the steps given above as needed.

26. ☐ Write your data run number here: __________

27. ☐ Save your file and clean up according to your teacher's instructions. �(11.1)

Sample Data

Temperature of the solar energy collection panel at three angles of insolation



Data Analysis

1. ☐ Find the minimum and maximum temperatures for each run of data and record them in Table 1 below.

a. Display the run of data you want to analyze. �(7.1.7)

b. Use the statistics tool to find the minimum and maximum temperature. �(9.4)

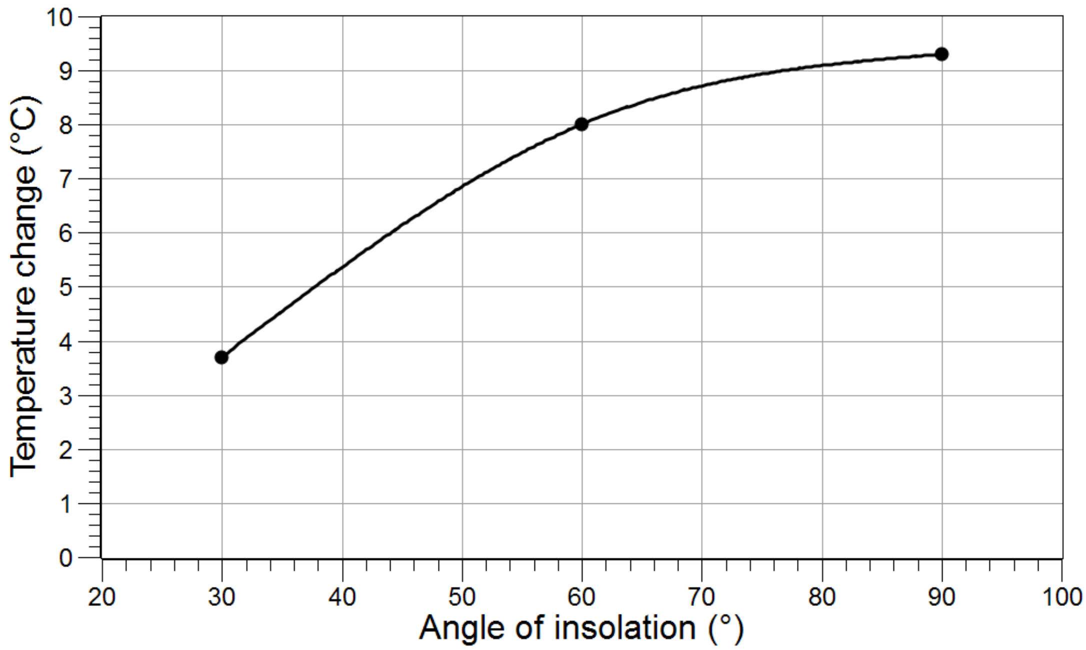
Table 1: Temperatures at 3 angles of insolation

Angle of Insolation	Minimum Temperature (°C)	Maximum Temperature (°C)	Change in Temperature (°C)
90°	39.4	48.7	9.3
60°	35.3	43.3	8.0
30°	36.3	40.0	3.7

2. ☐ Calculate the change in temperature for each run of data and enter the answers in Table 1 above.

3. ☐ Plot a graph of Temperature Change on the y-axis with Angle of Insolation on the x-axis. Label the overall graph the x-axis, the y-axis, and include a scale with units on the axes.

Temperature Change After Exposing a Solar Energy Collection Panel to Solar Radiation at Different Angles for Five Minutes



Analysis Questions

1. What effect did the angle of the sun have on the temperature of the solar energy collection panel? Use your data to support your answer.

The greater the angle of insolation was, the larger the change in temperature. At 90° the change in temperature was 9.3 °C, at 60° the change in temperature was 8.0 °C, and at 30° the temperature change was only 3.7 °C.

2. What is the independent variable and dependent variable in this experiment?

The independent variable was the angle of insolation. The dependent variable was the temperature of the solar energy collection panel.

3. How did the procedure in this lab simulate solar radiation received by cities with different latitudes?

The solar energy collection panel was aligned at different degrees of insolation which is similar to the way that cities at different latitudes receive solar radiation at different angles.

4. Would you expect the results of this experiment to change if you performed the lab six months from now? Why or why not?

The relationship between the angle of insolation and the temperature would not change because the lab procedure changes the angle of insolation by moving the solar energy collection panel which should always give the same results. The values of the temperatures (minimum, maximum, and change in temperature), however, would likely be different because data would be collected in a different season.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Mars is tilted 25.1° on its axis in relation to its path around the Sun. Given this information, predict whether or not you would expect Martian weather to be subject to seasonal variations.

Yes, Mars has seasons for the same reasons that Earth has seasons – different parts of the planet receive different angles of insolation at different times of year as the planet revolves about the sun.

2. Why are seasons more pronounced the further you move away from the equator?

The seasons are more pronounced the further you move away from the equator because the changes in the angles of insolation are more extreme as you move towards the poles.

Multiple Choice Questions

Select the best answer or completion to each of the question or incomplete statements below.

1. If you repeated the same experiment using the angles listed below, which one would you expect to see the greatest change in temperature?

- **A.** 20°
- **B.** 40°
- **C.** 60°
- **D.** **80°**
- **E.** 100°

2. Which of the following affect seasonal temperature changes the most?

- **A.** Distance of the Earth from the Sun
- **B.** **Tilt of the Earth on its axis**
- **C.** Rotation of the Earth on its axis
- **D.** Distance of the Moon from the Earth
- **E.** All of the above affect seasonal temperatures equally

3. At the Spring and Fall equinoxes, the earth's North Pole is

- **A.** Tilted towards the sun relative to the South Pole.
- **B.** Tilted away from the sun relative to the South Pole.
- **C.** **The same distance from the sun relative to the South Pole.**
- **D.** It depends on whether it is spring or fall.
- **E.** Both A and B are correct.

4. Which of the following terms refers to the intensity of incoming solar radiation that strikes a given surface on Earth at a given time?

- **A.** Insulation
- **B.** **Insolation**
- **C.** Intensity
- **D.** Perihelon
- **E.** Solstice

5. How do seasons in the Southern Hemisphere and Northern Hemisphere compare?

- **A.** They are the same and occur at the same time each year.
- **B.** **They are the same but occur at opposite times of year. When it is summer in the Northern Hemisphere it is winter in the Southern Hemisphere.**
- **C.** They are the same but are one season off. When it is summer in the Northern Hemisphere it is spring in the Southern Hemisphere.
- **D.** There are a completely separate set of seasons in the two different hemispheres.
- **E.** The Southern Hemisphere does not have winter, but they do have the other seasons.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Annual temperature changes or **seasons** on planets are controlled by the amount of **insolation** that reaches the planets. Insolation is defined as the intensity of incoming solar **radiation** that strikes a given surface on a planet at a given time. Two factors, the **distance** from the Sun and the tilt of the planet's **axis**, control the amount of insolation. On Earth, with its **elliptical** orbit, the distance from the Earth to the Sun varies by only 5 million kilometers (average distance from the Sun is about 150 million kilometers) over the course of one year. If distance were the main factor controlling the seasonal temperature variations, then when the Sun was the closest to the Earth during its orbit (called the **perihelion**) we would expect the amount of energy to be highest and lowest when it is furthest away (called the **aphelion)**. Earth is closest to the Sun around January 4th, which in the Northern Hemisphere is the middle of winter and furthest from the Sun in early July during the middle of the summer! Therefore, the second factor, the tilt of Earth's axis, must be the controlling factor.

2. At any point during the day, the amount of **energy** that a particular part of the Earth receives changes. The daily change is due to Earth's **rotation,** that is the spinning of Earth on an **imaginary** line called the **axis** of rotation. One half of the Earth receives sunlight, while the other half receives none. During rotation, the amount of sunlight reaching a specific location can vary due to terrain, **latitude**, and a multitude of other factors.

3. The December **solstice**, December 20 or 21, is the **shortest** day of the year in the Northern Hemisphere and the **longest** day of the year in the Southern Hemisphere. It is the beginning of **winter** in the Northern Hemisphere and the beginning of **summer** in the Southern Hemisphere. The June **solstice**, June 20 or 21, is the **longest** day of the year in the **Northern** Hemisphere and the shortest day of the year in the **Southern** Hemisphere. It is the beginning of **summer** in the Northern Hemisphere and the beginning of **winter** in the Southern Hemisphere. The March **equinox**, March 20 or 21, is the day when there are 12 hours of daylight and 12 hours of night in both the Northern and Southern Hemispheres. It is the beginning of **spring** in the Northern Hemisphere and the beginning of **fall** in the Southern Hemisphere. The September equinox, September 22 or 23, is the day when there are 12 hours of daylight and 12 hours of night in both the Northern and Southern Hemispheres. It is the beginning of fall in the **Northern** Hemisphere the beginning of spring in the **Southern** Hemisphere**.**

Extended Inquiry Suggestion

Challenge students to use available resources to conduct a comparison of latitude and change in minimum and maximum temperatures of various cities worldwide. If you have *My World GIS* available, this would be a good query.