

## **ES 106 Laboratory # 5**

### **EARTH-SUN RELATIONS AND ATMOSPHERIC HEATING**

#### **Introduction**

*Weather* is the state of the atmosphere at a particular place for a short period of time. The condition of the atmosphere at any place and time is described by measuring the four basic elements of weather: temperature, humidity, air pressure, and wind. Of all the controls that are responsible for causing global variations in the weather elements, the amount of solar radiation received at any location is certainly one of the most important. Investigating the journey of solar radiation and how it is influenced and modified by air, land, and water will provide a better understanding of one of the most basic weather elements, atmospheric temperature.

*Temperature* is an important element of weather and climate because it greatly influences air pressure, wind, and the amount of moisture in the air. The single greatest cause of temperature variations over the surface of Earth is differences in the reception of solar radiation. Secondary factors such as the differential heating of land and water, ocean currents, and altitude can also modify local temperatures. The unequal heating that takes place over the surface of the Earth is what sets the atmosphere in motion, and the movement of air is what brings changes in our weather.

For life on this planet, the relations between Earth and the sun are perhaps the most important of all of the astronomical phenomena. The amount of solar energy (radiation) striking earth is not constant throughout the year at any particular place but varies with the seasons. However, the total amount of radiation that the planet intercepts from the sun equals the total radiation that it loses back into space. It is this balance between incoming and outgoing radiation that keeps Earth from becoming continuously hotter or colder

#### **Goals and Objectives**

- Examine what happens to solar radiation as it enters and interacts with the Earth system
- Examine the effect that sun angle has on the intensity and duration of solar radiation that any particular location receives throughout the year.
- Diagram the relationship between Earth and the sun on the dates of the solstices and equinoxes.
- Explain how the heating of a surface is related to its albedo and consider the differences in the heating and cooling of land and water.

Name \_\_\_\_\_ **KEY** \_\_\_\_\_

Lab Day/Time \_\_\_\_\_

Pre-lab Questions – Complete these questions before coming to lab.

1. Define the following terms:

A. Equinox

**DAYS OF THE YEAR WHEN SUNLIGHT AND DARKNESS ARE EQUAL ALL OVER THE WORLD. THIS OCCURS ON OR ABOUT MARCH 21 AND SEPTEMBER 21, WHEN EARTH'S AXIS IS TANGENT TO ITS ORBIT AROUND SUN. SUNLIGHT FROM DIRECTLY OVERHEAD AT EQUATOR.**

B. Solstice

**DAYS OF THE YEAR WHEN SUNLIGHT IS SHINING DIRECTLY OVERHEAD AT ITS MOST POLEWARD, AT THE 'TROPIC' OF: CANCER ON OR ABOUT JUNE 21, AND CAPRICORN ON OR ABOUT DECEMBER 21. DAY LENGTH IS MOST EXTREME ON THE SOLSTICE.**

C. Infrared radiation

**TYPE OF ELECTROMAGNETIC RADIATION THAT IS HEAT: LONGER IN WAVELENGTH, AND LOWER IN FREQUENCY THAN VISIBLE LIGHT.**

D. Albedo

**MEASURE OF REFLECTANCE OF VISIBLE LIGHT, REPORTED IN PERCENT.**

2. If a  $4 \text{ cm}^2$  surface absorbs 8 langleys of solar radiation, how many calories of energy would it have received? (Show formula for calculations, with units. One Langley equals one calorie per square centimeter.)

$$8 \text{ LANGLEYS} = 8 \text{ cal/cm}^2$$

$$4 \text{ cm}^2 \times 8 \text{ cal/cm}^2 = 32 \text{ cal}$$

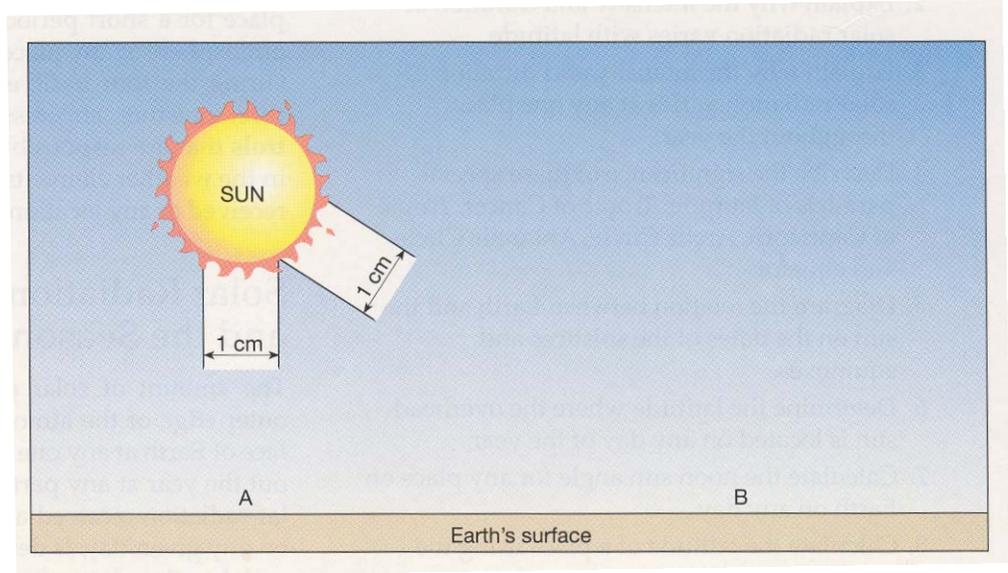
3. The amount of solar energy per unit area hitting the top of the Earth's atmosphere is greater than the amount that actually reaches the Earth's surface. Give at least three factors that contribute to the decrease in the amount of energy reaching Earth's surface and explain each.

**ABSORPTION BY ATMOSPHERE: MOLECULES GAIN ENERGY FROM SOLAR INPUT**

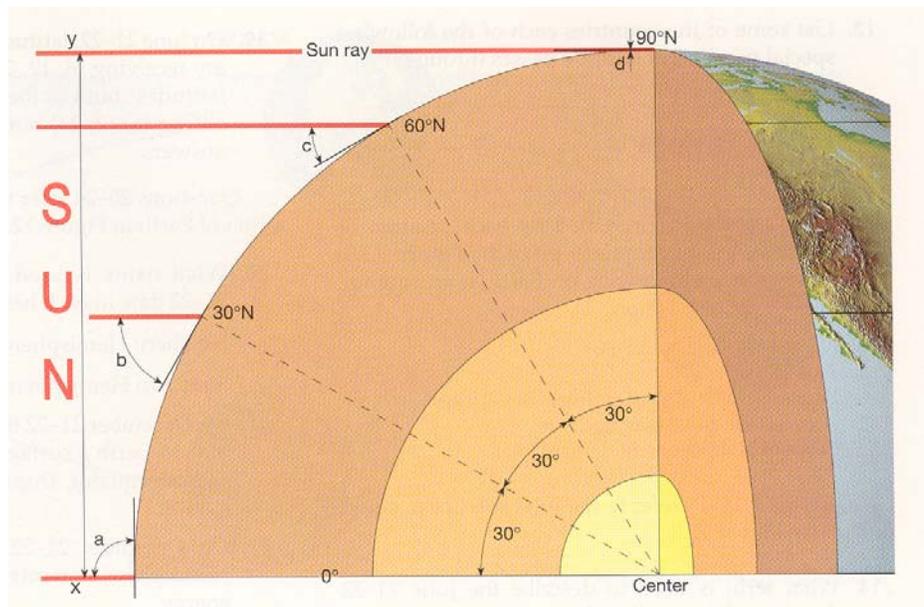
**REFLECTION BY WATER VAPOR ETC.: RETURNED TO SPACE WITHOUT CHANGING ATMOSPHERIC ENERGY**

**SCATTERING BY PARTICLES: BROKEN INTO SMALLER ENERGY PACKETS AND DISBURSED THROUGHOUT ATMOSPHERE**

**Figure 1**  
Vertical and oblique sun beams.

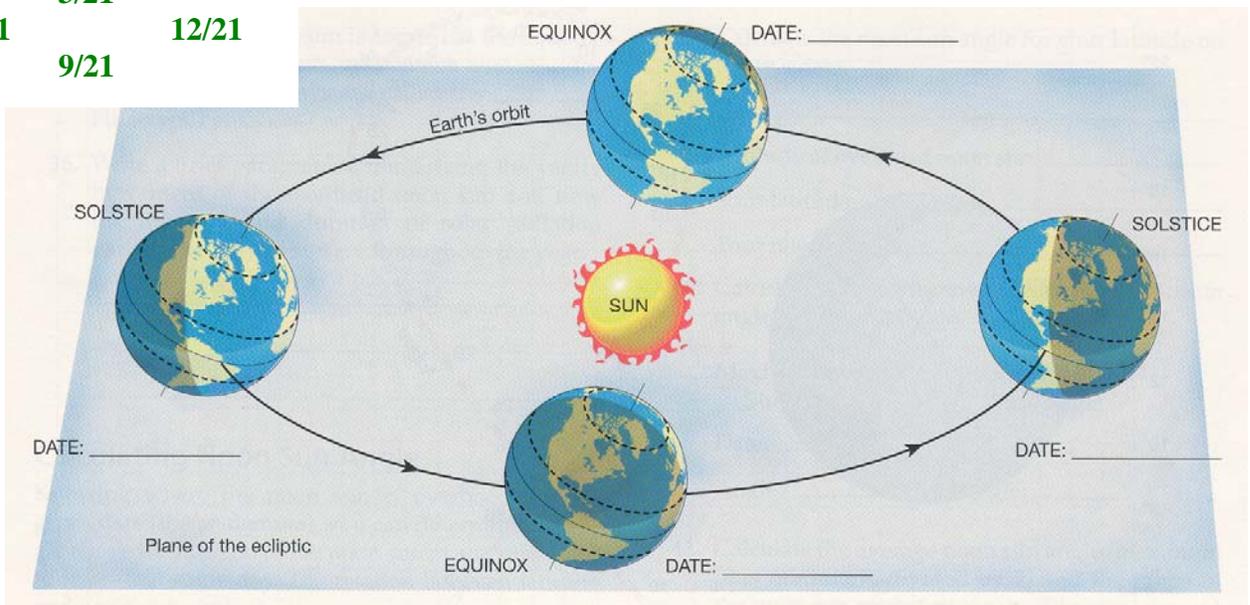


**Figure 2**  
Distribution of solar radiation per 30° segment of latitude on the Earth.



**Figure 3**  
Earth-sun relations

3/21  
6/21      12/21  
9/21



## Part A – Solar Radiation and the Seasons

The amount of solar energy (radiation) striking the outer edge of the atmosphere is not uniform over the face of Earth at any one time, nor is it constant throughout the year at any particular place. The intensity and duration of sunlight determine the amount of solar radiation received at any particular place on Earth on any given day. *Intensity* is the amount of solar energy per unit area per unit time that hits a given surface and is determined by the angle at which the rays of sunlight strike the surface. *Duration* refers to the length of daylight. The standard unit of solar radiation is the *langley*, equal to one calorie per square centimeter. The solar constant, or average intensity of solar radiation falling on a surface perpendicular to the solar beam at the outer edge of the atmosphere, is about 2 langleys per minute. As the radiation passes through the atmosphere, it undergoes absorption, reflection, and scattering. Therefore, at any one location, less radiation reaches Earth's surface than was originally intercepted at the upper atmosphere.

### Activity 1: Sun Angle Solar Radiation and Latitude

The amount of radiation striking a square meter at the outer edge of the atmosphere, and eventually Earth's surface, varies with latitude because of different **sun angles** at different latitudes. On Figure 1, extend the 1 cm wide beam of sunlight from the Sun vertically to point A on the surface. Extend the second 1 cm wide beam, beginning at the sun, to the surface at point B. Notice that the sun is directly overhead (vertical) at point A and the beam of sunlight strikes the surface at a 90° angle above the horizon.

- Using a protractor, measure the angle between the surface and the beam of sunlight coming from the sun to point B. 31° = angle of sun above the surface at point B.
- What are the lengths of the line segments, in millimeters, on the surface covered by the sunbeam at point A and point B?  
Point A: 10 mm; Point B: 19 mm
- Of the two beams, which is more spread out at the surface and covers a larger area. B
- Which surface would receive more langleys per minute? A

Use Figure 2 to answer questions concerning the total amount of solar radiation intercepted by each 30° segment of latitude on Earth.

5. With a metric ruler, measure the total width of incoming rays from point *x* to point *y* in the figure. The total width is 7 cm (70 mm).
6. Assume the total width of the incoming rays from point *x* to point *y* equals 100% of the solar radiation that is intercepted by Earth. Each centimeter would equal 14.28% and each millimeter would equal 1.43%.
7. What percentage of the total incoming radiation is concentrated in each of the following zones? (Hint: Measure the total distance in mm and multiply by %/mm from above.)
  - 0° - 30° = 35 mm = 50%
  - 30° - 60° = 25 mm = 36%
  - 60° - 90° = 10 mm = 14%
8. Use a protractor to measure the angle between the surface and sunray at each of the following locations. (Angle b is already done as an example.)

Angle a: 90°

Angle b: 60°

Angle c: 27°

Angle d: 0°

9. What is the general relationship between the amount of radiation received in each 30° segment and the angle of the sun's rays?

**DECREASES FOR EACH SEGMENT FROM EQUATOR**

10. Provide a simplified sketch and briefly explain in your own words what fact about Earth creates the unequal distribution of solar energy, even though each zone represents an equal 30° segment of latitude.

**SKETCH: SEE FIGURE 2**

**EARTH'S CURVATURE RESULTS IN SOLAR RADIATION BEING SPREAD OUT OVER LARGER AREAS IN HIGH LATITUDES**

## Activity 2: Yearly Variation in Solar Energy

The amount of solar radiation received at a particular place would remain constant throughout the year if it were not for these facts:

- ◆ Earth rotates on its axis and revolves around the sun.
- ◆ The axis of Earth is inclined  $23\frac{1}{2}$  degrees from perpendicular to the plane of orbit.
- ◆ Throughout the year, the axis of Earth points to the same place in the sky. This causes the overhead noon sun to cross over the equator twice as it migrates from the Tropic of Cancer ( $23\frac{1}{2}$  degrees N latitude) to the Tropic of Capricorn ( $23\frac{1}{2}$  degrees S latitude) and back to the tropic of Cancer.

As a consequence, the position of the overhead noon sun shifts between the hemispheres, causing variations in the intensity of solar radiation and changes in the length of daylight and darkness. The seasons are the result of this changing intensity and duration of solar energy and subsequent heating of the atmosphere.

1. On Figure 3, write the date / season represented by each position of Earth at the appropriate place on the figure.
  
2. What term is used to describe the June 21-22 date in each hemisphere?  
 Northern Hemisphere: \_\_\_**SUMMER**\_\_\_\_\_ solstice  
 Southern Hemisphere: \_\_\_**WINTER**\_\_\_\_\_ solstice
  
3. What latitude is receiving the most intense solar energy on June 21-22?  
 Latitude: \_\_\_**23.5° N**\_\_\_\_\_
  
4. On June 21-22, latitudes north of the Arctic Circle are receiving (0 / 6 / 12 / **24**) hours of daylight, while latitudes south of the Antarctic Circle are experiencing (**0** / 6 / 12 / 24) hours of darkness. (Circle appropriate responses.)
  
5. What name is used to describe the December 21-22 date in each hemisphere?  
 Northern Hemisphere: \_\_\_\_\_**WINTER**\_\_\_\_\_ solstice  
 Southern Hemisphere: \_\_\_\_\_**SUMMER**\_\_\_\_\_ solstice
  
6. On December 21-22, the (Northern / **Southern**) Hemisphere is receiving the most intense solar energy. (Circle appropriate response.)

Table 1: Length of daylight.

Latitude (degrees)	Summer Solstice	Winter Solstice	Equinoxes
0	12 h	12 h	12 h
10	12 h 35 min	11 h 25 min	12
20	13 12	10 48	12
30	13 56	10 04	12
40	14 52	9 08	12
50	16 18	7 42	12
60	18 27	5 33	12
70	24 h (for 2 mo)	0 00	12
80	24 h (for 4 mo)	0 00	12
90	24 h (for 6 mo)	0 00	12

7. Use the Table 1 to find how many hours of daylight there would be at each of the following latitudes on December 21-22.

90 degrees N:   0   hrs   0   min

40 degrees N:   9   hrs   8   min

0 degrees:   12   hrs   0   min

40 degrees S:   14   hrs   52   min

90 degrees S:   24   hrs   0   min

8. For those living in the Northern Hemisphere, what terms are used to describe the following dates?

March 21:   SPRING   equinox

September 22:   AUTUMN   equinox

9. For those living in the Southern Hemisphere, what terms are used to describe the following dates?

March 21:   AUTUMN   equinox

September 22:   SPRING   equinox

10. What latitude is receiving the most intense solar energy on March 21 and September 22?   0°

11. Describe the length of daylight everywhere on earth on March 21 and September 22.

**DAY LENGTH IS 12 HOURS ALL OVER THE WORLD ON THE EQUINOX**

## Part B – The Nature of the Earth’s Surface and Atmospheric Heating

The various materials that comprise Earth’s surface play an important role in determining atmospheric heating. Two significant factors are the albedo of the surface and the different abilities of land and water to absorb and reradiate radiation. *Albedo* is the reflectivity of a substance, usually expressed as the percentage of radiation that is reflected from the surface. Since surfaces with high albedos are not efficient absorbers of radiation, they cannot return much long-wave radiation to the atmosphere for heating. Most light-colored surfaces have high albedos, causing light-colored surfaces (and the air above them) to be typically cooler than dark surfaces.

Before getting started, predict which will have the higher albedo – the black can or the silver can.

### Activity 1: Albedo Experiment

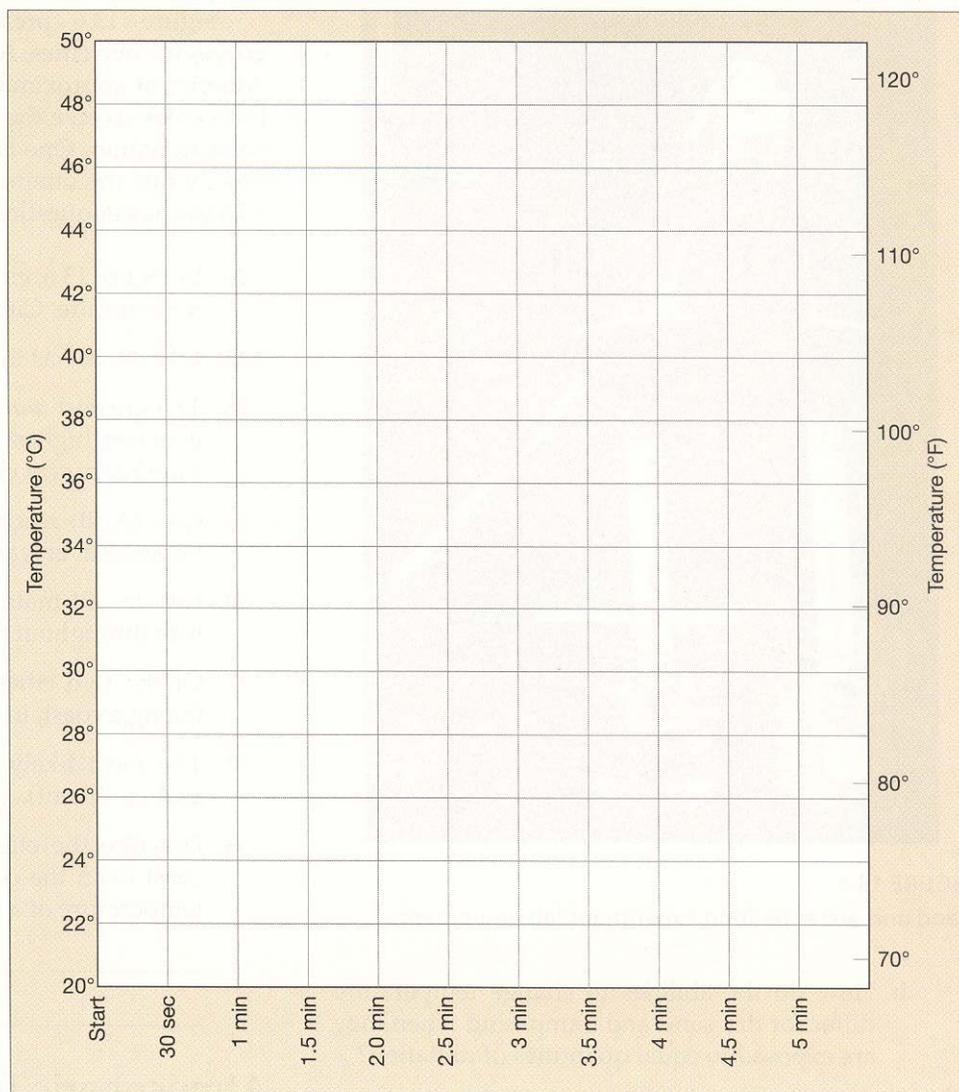
To better understand the effect of albedo on atmospheric heating, conduct the experiment below using the provided apparatus and answer the questions.

#### *Procedure:*

- Step 1: Place the black and silver containers (with lids and thermometers) about 6 inches away from the light source. Make certain that both containers are equal distance from the light and are not touching one another. Be sure that the light is shining on the sides of the cans and not on the white, foam lids.
- Step 2: Make sure that the cans have cooled back since the previous group did the experiment. Record the starting temperature of both containers in Table 2: Albedo Experiment Data.
- Step 3: Turn on the light and record the temperature of both containers on the data table at about 30-second intervals for 5 minutes.
- Step 4: Plot the temperatures from the data table on Figure 4, the albedo experiment graph. Use a different color line to connect the points for each container.

**Table 2:** Albedo Experiment Data.

	Starting Temp	30 sec	1 min	1.5 min	2 min	2.5 min	3 min	3.5 min	4 min	4.5 min	5 min
<b>Black Container</b>											
<b>Silver Container</b>											

**Figure 4:** Graph of data from the albedo experiment.**Questions:**

1. Which container has the higher albedo? \_\_\_\_\_ **SHINY** \_\_\_\_\_
2. Does this result match your prediction? **YES**
3. Write a brief statement that summarizes the results of the albedo experiment.  
**DARK OBJECTS ABSORB ENERGY RATHER THAN REFLECT IT**
4. List two examples of Earth surfaces or materials that have high albedos.  
**WATER, SNOW, ICE, CLOUDS, HIGH-GRADE METAMORPHIC ROCKS, OUTCROPS OF GLACIALLY-POLISHED ROCK, SALT, WHITE BEACH SAND CONCRETE, GLASS**
5. List two examples of Earth surfaces or materials that have low albedos.  
**SOIL, PLANT LITTER, BLACK BEACH SAND, DARK COLORED ROCK SUCH AS BASALT, ASPHALT**
6. Given equal amounts of radiation reaching the surface, the air over a snow-covered surface will be (**colder** / warmer) than air above a dark-colored, barren field. Explain your choice fully in terms of what you have learned about albedo.  
**SINCE THE SNOW-COVERED SURFACE REFLECTS THE LIGHT DIRECTLY, AND THE DARK FIELD ABSORBS IT (LOWER ALBEDO), THE DARK COLORED FIELD RE-EMITS THE ENERGY AS A LONGER WAVELENGTH: INFRARED, WHICH IS HEAT ENERGY**
7. Why is it wise to wear light-colored clothes on a sunny, hot day?  
**LIGHT COLORS HAVE HIGHER ALBEDO, DO NOT ABSORB THE ENERGY, BUT REFLECT IT.**
8. If you lived in an area with long cold winters, a (light- / **dark-**) colored roof would be the best choice. **BECAUSE IT WOULD ABSORB THE ENERGY, WARMING THE HOUSE**



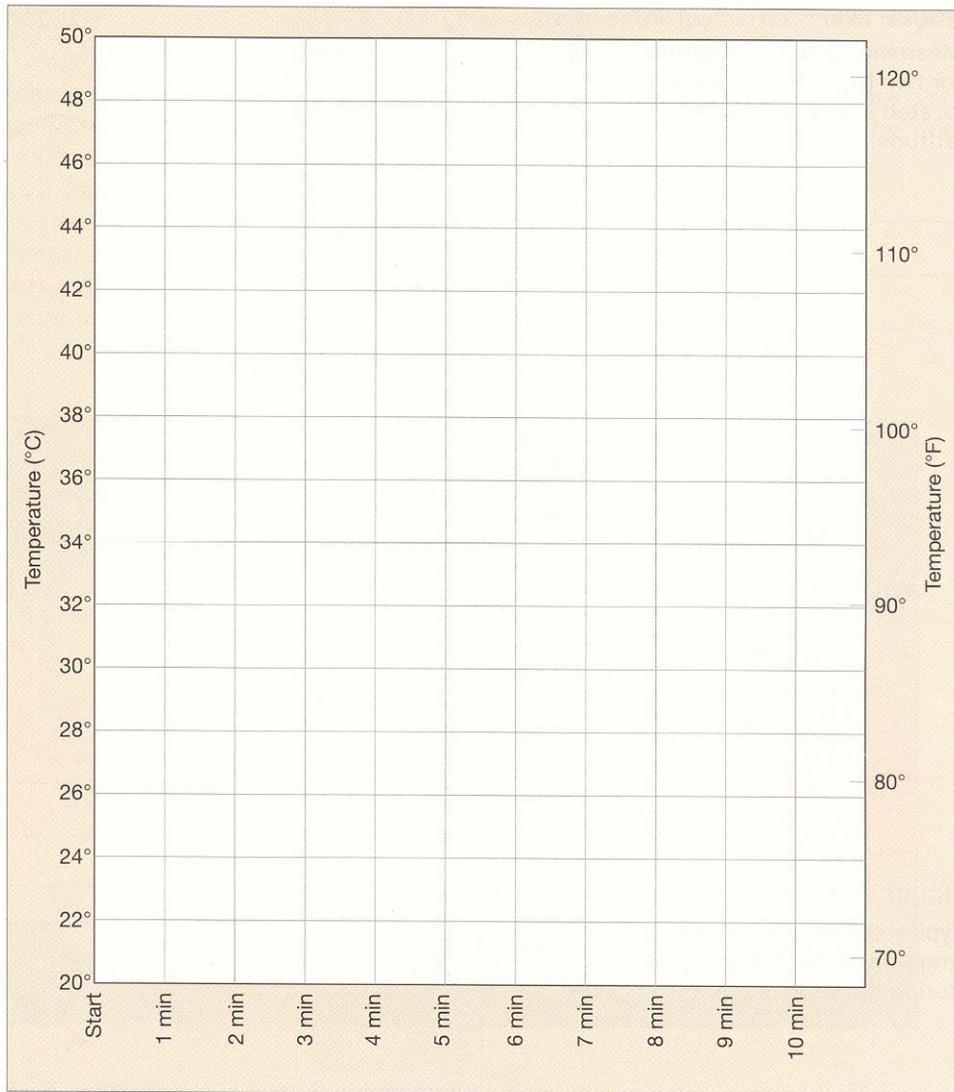


Figure 5: Graph for land and water heating experiment.

**Questions:**

1. How do the abilities to change temperatures differ for dry sand and water when they are exposed to equal amounts of radiation?

**THE SAND CHANGES TEMPERATURE MORE THAN THE WATER. THIS MAY BE DUE TO THE HIGH SPECIFIC HEAT CAPACITY OF WATER (ABOUT FIVE TIMES THAT OF SAND), THE CONVECTION OF THE WATER, TRANSFERRING HEAT FROM ITS SURFACE TO DEEPER LEVELS, OR WATER'S HIGH ALBEDO, REFLECTING THE ENERGY.**

2. List and thoroughly describe *two* reasons for the differential heating of land and water.

**THE SPECIFIC HEAT CAPACITY OF WATER IS MUCH GREATER THAN LAND—IT TAKES ABOUT FIVE TIMES AS MUCH ENERGY TO CHANGE THE TEMPERATURE OF WATER AS A SIMILAR MASS OF LAND. IN ADDITION, WATER IS FLUID, AND CAN MOVE THE HEAT TO ANOTHER PLACE, WHEREAS THE LAND IS FAIRLY STATIC. ALSO, WATER PROBABLY HAS HIGHER ALBEDO THAN LAND**

### Questions for Further Thought

Figure 6 presents the annual temperature curves for two cities, City A and City B, located in North America at approximately 37°-north latitude. On any given date, both cities receive the same intensity and duration of solar radiation. One city is in the center of the continent, while the other is on the west coast.

1. Answer the following questions using Figure 6.
  - a. Over the course of the year, City (A / B) has the highest monthly temperature.
  - b. Over the course of the year, City (A / B) has the lowest monthly temperature.
  - c. The greatest annual temperature range (difference between highest and lowest monthly temperatures) occurs at City (A / B).
  - d. City (A / B) reaches its maximum monthly temperature at an earlier date.
  - e. City (A / B) maintains a more uniform temperature throughout the year.
  - f. Of the two cities, City A is the most likely to be located (**along a coast** / in the center of a continent).
  - g. The most likely location for City B is (coastal / **mid-continent**).
2. Describe the effect that location (either along the coast or in the center of a continent) has on the temperature variations of a city throughout the year.

**MILD TEMPERATURES OCCUR IN COASTAL AREAS, MODERATED BY THE EFFECT OF A LARGE BODY OF WATER. AREAS ISOLATED FROM MARINE INFLUENCE, SUCH AS MID-CONTINENT AREAS HAVE GREATER TEMPERATURE VARIATIONS SEASONALLY AND DAILY, AND CAN BE MUCH COLDER IN WINTER, AND WARMER IN SUMMER, THAN COASTAL AREAS.**

Figure 7 shows how daily temperature varies for a typical mid-latitude city. In general, the daily temperatures that occur at any particular place are the result of long-wave radiation being released at the Earth's surface. However, secondary factors, such as cloud cover and cold air moving into the area, can also cause variations.

3. The coolest temperature of the day occurs at DAWN, and the warmest temperature occurs at 4-5 PM.

4. What is the daily temperature range (difference between maximum and minimum temperatures for the day), in degrees Celsius?

**12.5° C**

5. What is the daily mean temperature (average of maximum and minimum temperatures) in degrees Celsius?

**20.25° C**

6. Considering how the atmosphere is heated, why does the warmest daily temperature occur in the mid-to-late afternoon rather than at the time of the highest sun angle?

**MORE TIME FOR HEATING, SUBSTANCES WITH LOW ALBEDO ARE RE-RADIATING (EMITTING) AS HEAT, THE ENERGY ABSORBED EARLIER**

7. Why does the coolest temperature of the day occur about sunrise?

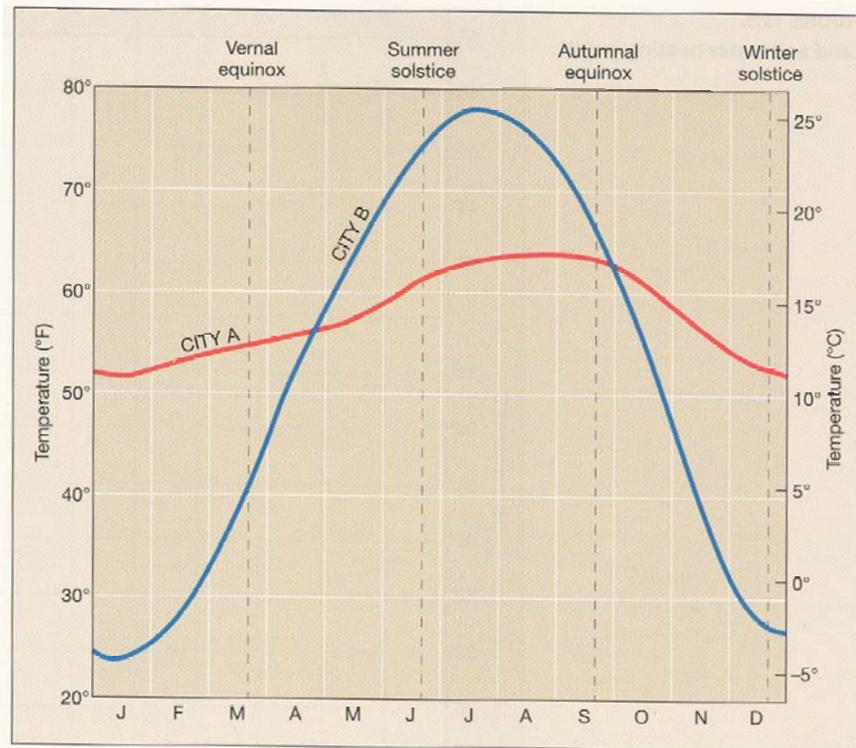
**LONGEST AMOUNT OF TIME FOR SUBSTANCES TO EMIT (RERADIATE) THE HEAT ABSORBED, AND LONGEST TIME SINCE SUN ENERGY PRESENT**

8. How would cloud cover influence daily maximum and minimum temperatures?

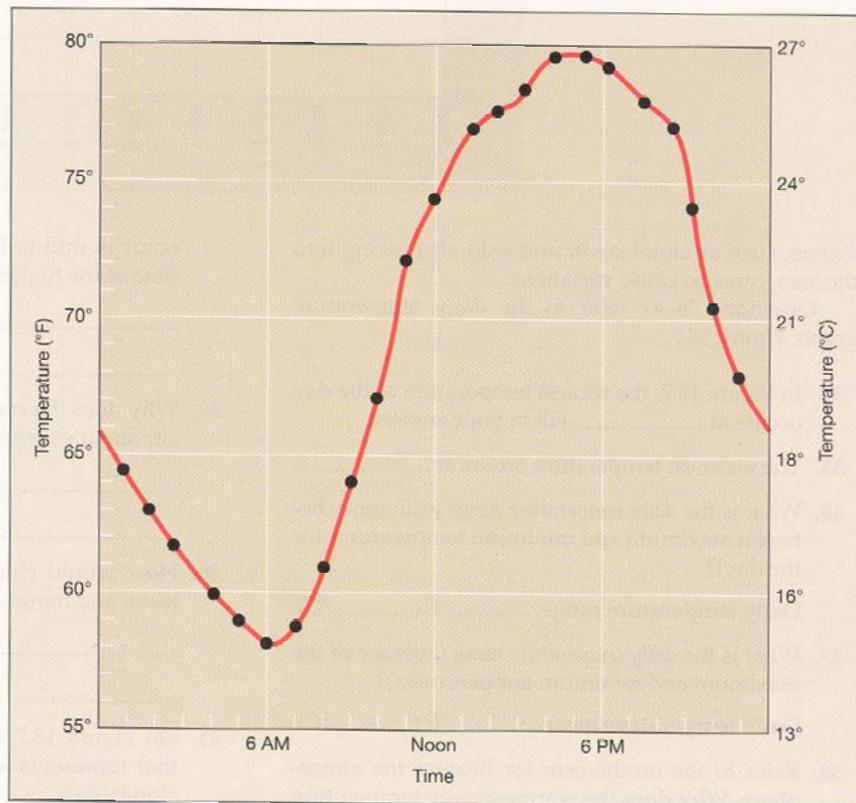
**CLOUD COVER WOULD KEEP DAILY MAXIMUM LOWER, BUT REFLECT RERADIATED HEAT AT NIGHT BACK TO SURFACE, KEEPING OVERNIGHT TEMPERARURES HIGHER.**

9. On Figure 7, sketch and label a line that represents a daily temperature graph for a cloudy day. **FLAT LINE, OR GENTLY SLOPED FROM DAWN TO DUSK**

**Figure 6**  
Mean monthly  
temperatures for two  
North American cities  
located at approximately  
37°N latitude.



**Figure 7**  
Typical daily  
temperature graph for  
a mid-latitude city  
during the summer.



Name \_\_\_\_\_ **KEY** \_\_\_\_\_

Lab Day/Time \_\_\_\_\_

**POST-LAB ASSESSMENT**

1. Imagine that you are designing a house that gets its heat and electricity from solar energy. The house is located in Oregon.

A. How would you want to angle the solar collector panels to receive the most energy from the Sun? Would the collectors face north, south, east or west? Would the collectors lie horizontally, vertically, or at an angle? Justify your answers.

**POINT SOLAR COLLECTORS SOUTH IN OREGON (BECAUSE IT IS THE NORTHERN HEMISPHERE). THE COLLECTORS WOULD BE MOST EFFICIENT IF THEY WERE AT AN ANGLE, COINCIDENT WITH SUN ANGLE, WHICH VARIES THROUGHOUT THE YEAR.**

B. Would the optimal orientation for the panels change during the day? How and why, or why not?

**YES, THE OPTIMAL ORIENTATION WOULD BE TO FOLLOW THE SUN FROM LOW EASTWARD ANGLE AT DAWN, TO HIGHER ANGLE TO SOUTH AT MID-DAY, AND TO WEST AT LOWER ANGLE IN LATE AFTERNOON.**

C. Would the optimum orientation change through out the year? How and why, or why not?  
**AS THE SUN'S ANGULAR HEIGHT IN THE SKY DIMINISHES FROM THE JUNE SOLSTICE TO THE DECEMBER SOLSTICE, AND INCREASES FROM DECEMBER TO JUNE, THE OPTIMUM ORIENTATION CHANGES CONTINUALLY THROUGHOUT THE YEAR.**

2. Using what you have learned in lab today, explain why deserts often have very cold nighttime temperatures.

**DESERTS ARE COLD AT NIGHT BECAUSE THERE IS LITTLE MOISTURE TO MODERATE THE TEMPERATURE, AND LITTLE CLOUD COVER TO REFLECT RADIATED HEAT FROM EARTH'S SURFACE BACK TO EARTH. IN ADDITION, MUCH DESERT SURFACE HAS HIGH ALBEDO, AND REFLECTS SUN ENERGY INSTEAD OF ABSORBING IT.**

3. Using what you have learned in lab today, explain why an expansion of ice sheets would lead to an over all cooling of the Earth's atmosphere. Be sure to consider what happens to incoming visible solar radiation when it hits a snowy or icy surface.

**IN ADDITION TO THE ICE COOLING THE AIR, ICE SHEETS HAVE HIGH ALBEDO, AND REFLECT INSTEAD OF ABSORB ENERGY FROM THE SUN. THE RESULT WILL BE AN OVERALL COOLING OF EARTH'S ATMOSPHERE.**