The Sun: The Earth's External Heat Engine

Part 2 of the Astronomy Model

Suggested Level: Grades 8 through 12, especially students who are enrolled in Regents Earth Science

LEARNING OUTCOME

As a result of constructing and using a model of the earth's orbit, students are able to cite examples of variables that affect energy availability at the earth's surface and explain why such variations take place.

LESSON OVERVIEW

In this lesson, students work with the variables that control the earth's solar energy supply.

• Previously, in Part 1, students developed mathematical models, making calculations having to do with two astronomical variables that help control heat energy on the earth. Students typically overestimate the importance of these variables in controlling heat gain by the earth.

• In Part 2, a scale model of the earth's orbit is mathematically modeled and evaluated, locations of the earth on that orbit are determined, and a model of the earth is used to study the effect of latitude on the availability of sunlight energy at the earth's surface. Also, models of the earth are used to measure sunlight angles at solar noon and to compare length of daylight for various latitudes at the solstices and equinoxes.

MATERIALS

- Light source (clip light of 100 watts mounted on stand)
- Teacher's chalkboard compass with chalk
- Washable marker
- Calculator
- 4-inch hard styrofoam Dylite ball
- 9-inch section of ¼-inch hardwood dowel
- 5-inch section of 1/8-inch dowel
- Wooden base
- Flexible ruler
- Ultimate protractor

SAFETY

Alert students to be careful when working near the light source's hot light bulb. Tell them to avoid knocking over or dropping that device.

TEACHING THE LESSON

Set aside three class periods for this lesson: two periods plus homework time to complete the activity and one period for post-lab discussion and explanations.

Students will already have completed a laboratory activity in which they construct models of the earth and study the nature of ellipses; in this activity, they learn the importance of ellipses in the movement of astronomical bodies.

You should allocate sufficient time for the construction of the earth models. These models can be made from readily available, inexpensive materials that typically may be obtained in a craft store. It is important to drill the hole in the base at a right angle. You may want to seek the help of your local technology education teacher, who will have a drill press, when doing this part of the activity. Also, it is recommended that you insert the “pole” all the way through the model to provide better support when marking the latitude lines. Relative dimensional data are in Worksheet 1: The Earth’s Orbit.

The protractors should be modified by grinding out the underside so that their dimensions will be accurate and they will fit snugly against the earth model and be easier to use. Use a 4-inch grinding wheel mounted on a grinder for this job. Once again, using the equipment in a technology education facility may prove helpful.

Worksheet 1 includes a review of orbits but imparts a different perspective to the nature of ellipses than is typically taught. The length of the minor axis in relation to the major axis is emphasized. This section is probably best introduced at the end of class, assigned as homework, and then reviewed/corrected the next day. Once all students have this portion of the lesson under control, the manipulative section can be initiated. The orbit should be drawn in chalk on the top of two standard laboratory tables, using a teacher’s chalkboard compass.

Student groups should be assigned latitudes at your discretion: any values from 0 to 90 can be used. Post-lab discussions should focus on the significance of latitude in determining solar energy availability in regions of the earth’s surface. This occurs both through the dilution of incoming sunlight, which is spread over larger areas of the earth’s surface as the poles are approached, and through the changes in the length of the solar day that occur with changes in both latitude and seasons.

ACCEPTABLE STUDENT RESPONSES

Answers to Worksheet 1:

1. .017

2. L = 2X + .017

3. 1 = 2X + .017

4. 2X = 1 - .017 = .983; X = .4915

5. X + d = .4915 + .017 = .5085

6. Aphelion: Perihelion

7. 2X + 2d = .983 + .034 = 1.017

8. $C^2 = A^2 + B^2$

   $(FB)^2 = (BC)^2 + (CF)^2$

   $.5^2 = .0085^2 - (CF)^2$

   $(CF)^2 = .25 - .00007225 = .24992775$

   CF = square root .24992775 = .4999277 = .4999

9. (1) .5000; (2) .4999; (3) very nearly circular

Answers to Procedures Questions:

1. Yes

2. 314.16 centimeters: smaller; .86 cm

3. 13 days; 11.2 cm

4. 13 days; 11.2 cm

5. April 3; October 3

[D. Each position is 9.5 cm before the end of the axis.]

1. Variable: on June 21 north of the equator; on December 21 south of the equator.

2. Variable: on June 21 north of the equator; on December 21 south of the equator.

3. Variable according to latitude, but in general more energy is received during times of greatest duration of insolation and greatest angle of noontime sunlight.

4. The sun is north of the equator between March 21 and September 22; it is south of the equator during the rest of the year. The amount of the sun's energy received at the equator peaks on the equinoxes.

5. The sun shines 24 hours (maximum duration) a day in June and reaches its highest elevation (greatest intensity) during that time.

6. Variable: student answers should vary because of measuring variations.

BACKGROUND INFORMATION

The orbit of the earth with its eccentricity of .017 is very nearly circular. This lab quantifies that fact by students determining the relative lengths of both the major and minor axes of that orbit. Most of the change in earth-to-sun distance is the result of the offset of the sun along the major axis away from the orbit center to one of the foci positions.

The angle of the noontime sun can be easily measured on the earth models by pointing the stick of the academic compass directly at the source of light. This angle should be equal to 90° minus the latitude at both equinox dates with 23½ degrees more on June 21 in the Northern Hemisphere (23½ degrees less in the Southern Hemisphere). On December 21 the opposite is true. Also, the length of the daylight period varies in a predictable way during the year. The attached solar pathways at selected latitudes will give the general idea. You may want to make transparencies of these figures for the post-lab discussion since these figures (or at least the top half of them) frequently appear on the Regents exam in Earth Science. Figure 2 provides a more graphic representation of the duration of insolation, while Figure 1 provides some surprising information regarding the amount of insolation received at various latitudes. A *langley* is a unit of energy equal to one gram calorie (the amount of energy needed to raise the temperature of one gram of water by one degree Celsius; 252 calories = 1 Btu) of heat received by one square centimeter of surface.

(STUDENT HANDOUT FOLLOWS)

Name ____ Date ____________

THE SUN: THE EARTH'S EXTERNAL HEAT ENGINE - Part 2 of the Astronomy Model

Materials needed:

- Clip light on stand
- Earth model on stand
- Marker
- Calculator
- Flex ruler
- Ultimate protractor
- Teacher's chalkboard compass with chalk
- Student compass
- Calendar

Procedures:

Step 1: Complete Worksheet 1: The Earth's Orbit.
Step 2: On your desktop, construct a model of the earth's orbit, using chalk (or if your teacher prefers, paper and markers). Be careful not to erase your lines and points as you work. Convert the length-of-axis values you calculated in Worksheet 1, using a scale of .01 cm = 1 cm for your model. (You may want to make a sketch showing locations and distance before you attempt the actual scale construction.)

1. Can you use a compass to do this job with reasonable accuracy? _______

A. Draw the major and minor axes and mark where the sun needs to be positioned.
B. Mark and label the position of perihelion and aphelion and write down their dates.
C. Mark the position of summer and winter solstices. (How can you determine these locations? HINT: Perihelion occurs on January 3 and aphelion occurs on July 4.)

2. Determine the circumference of the orbit you constructed. Because it is essentially a circle, the circumference = pi times the diameter.
The circumference is _______________________.
Although the speed of the earth in orbit varies slightly as the earth-to-sun distance changes (speeding slightly as the distance gets ___________________), we can assume an almost constant speed for our model's purposes. Therefore, in one day's time, our model earth will travel ____________________ centimeters (to the nearest hundredth).

3. Because our model earth will travel in a counterclockwise direction around its orbit, and because winter solstice occurs on December 21, calculate how many days before perihelion the solstice will occur:______________. Calculate the distance along the orbit between winter solstice and perihelion: ________________ centimeters (to the nearest tenth).

4. What is the number of days _________________ and distance ___________ ahead of aphelion for summer solstice (June 21)?

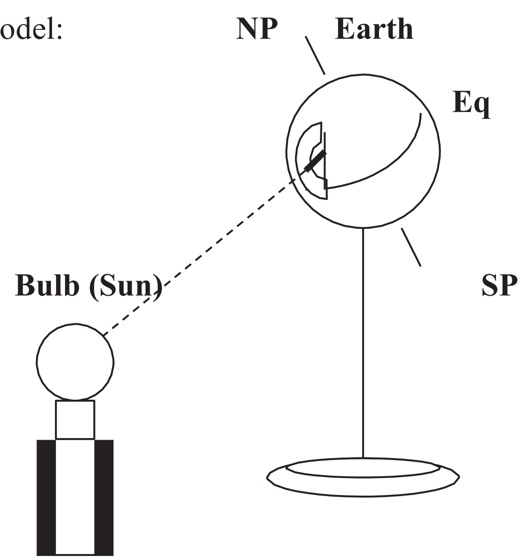
5. What are the dates at the ends of the minor axis? (Use a calendar to count the days after you have calculated the number of days from the end of the major axis.)
Date of minor axis at spring end: ___________________
Date of minor axis at fall end: ___________________

D. Locate both the spring (March 21) and fall (September 22 or 23) solstices. Mark and label these locations.

E. Have your teacher check your scale orbit model before you go on to the data-collection portion of the lab below.

Step 3: Data collection using the earth model:

You have three tasks to perform on this portion of the lab exercise: A. Measure the angle of the noontime sun for the latitude you have been assigned. B. Determine the number of hours of daylight for the collection dates (equinoxes and solstices). [Make sure you keep your earth model oriented in the same direction in relation to the classroom throughout the data-collection process.] C. Fill in the data chart with your information.



A. To measure the angle to the noon sun, hold the protractor as shown in the diagram and center the pivot point of the modified protractor on your assigned latitude line. Point the movable pointer directly at the sun. Read the angle on the side of the pointer that is in line with the pivot point of the protractor. Record your data for each of the four dates in the chart below.

B. To determine the length of day at your latitude, measure the length of your latitude line in the sunshine (bulb light) and divide that distance by the total distance of your latitude line around the earth. Multiply that result by 24 hours as shown by the formula below.

$$\frac{\text{Length of latitude in sunshine}}{\text{Total length of latitude line}} \times 24 \text{ hours} = \frac{\_\_\_\_\_\_ \text{cm.}}{\_\_\_\_\_\_\_\_\_\_\_\_ \text{cm.}} \times 24 \text{ hr.} = \_\_\_\_ \text{ hours}$$

Our assigned latitude is: _________ degrees N or S (circle one). To accurately determine the location of your latitude on the earth model, measure .9 centimeters north or south of the equator for each 10 degrees of latitude.

Data Table:

TIME OF YEAR	ANGLE OF NOON SUN	LENGTH OF DAYLIGHT
March 21		
June 21		
September 22		
December 21		

DEVELOP YOUR UNDERSTANDING

1. When during the year did your latitude receive the most direct (highest angle of) noontime sunlight? ______________________________

2. When did your latitude have the greatest duration (greatest number of hours of sunlight) per day of insolation? ______________________________

3. Carefully study Figure 1 below. Draw a line on Figure 1 that best represents the amount of heat energy (in langleys) received from the sun each day during the year at your assigned earth latitude.

   What is the relationship between the time of greatest duration of insolation at your assigned earth latitude and the time when your latitude received the greatest amount of energy from the sun? ____

   ____

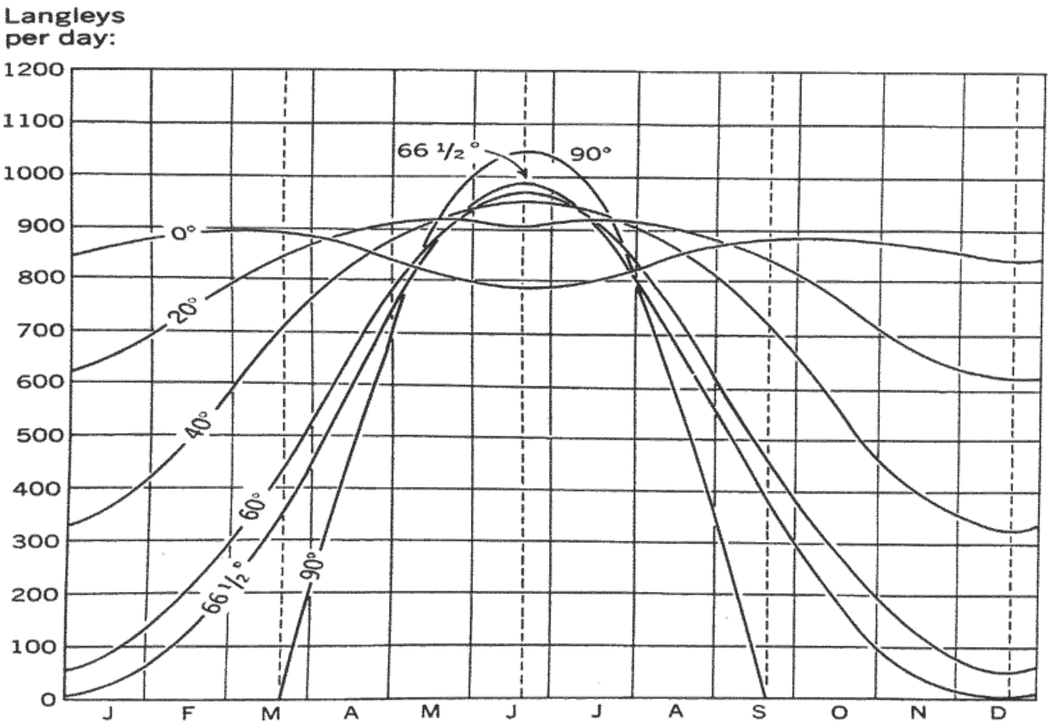


FIGURE 1 *Annual variation in daily insolation at selected latitudes in the Northern Hemisphere. (Data from Smithsonian Institution, Washington, D.C.)*

4. How do you explain the pattern of change in the amount of insolation received at the equator during the year? ______________________________

____

____

5. What best explains why the North Pole receives the greatest amount of sunlight energy during the month of June (and also the greatest monthly amount of any earth location)? ______________________________

____

____

6. Look at Figure 2 below. The left side of this figure is a graph that shows the time of sunrise at most latitudes during the year. The right side of the figure shows the time of sunset. Fill in the chart below to determine the length of daylight for your model's assigned latitude.

Time of Year	Time of Sunrise	Time of Sunset	Length of Daylight
March 21			
June 21			
September 22			
December21			

Does your length-of-day data, from your analysis of the earth model recorded in the data chart earlier, agree with the information on this chart? ______________________________

In what way or ways is your data different?

____

____

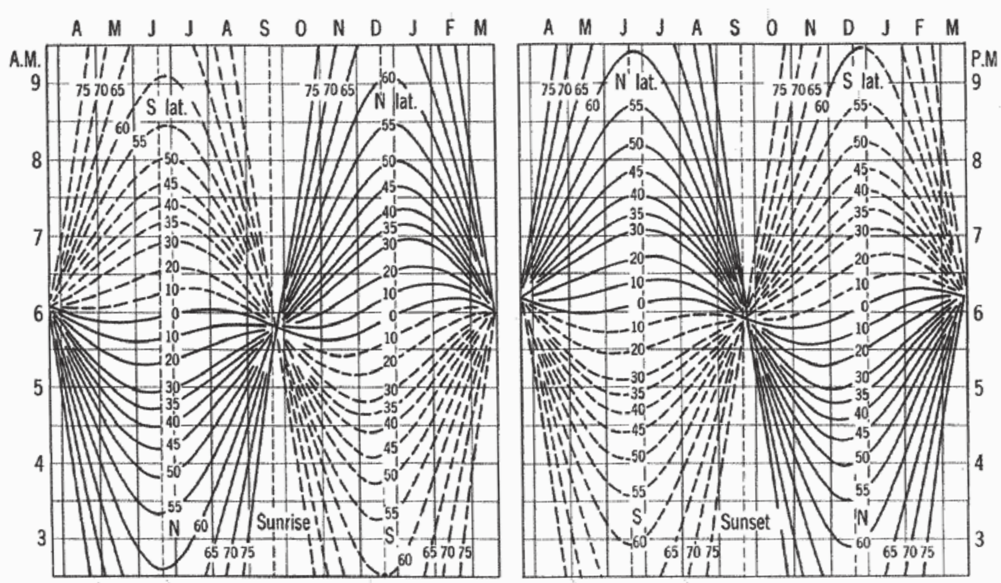


FIGURE 2 Sunset-sunrise diagram. Simplified from U.S. Navy Oceanographic Office

Name ______________________________ Date ____________

Worksheet 1: The Earth's Orbit

You have probably constructed models of elliptical orbits using tacks and string. In this lab exercise, we are going to take a slightly different approach to modeling the orbit of the earth around the sun. You know that the orbit of the earth is an ellipse and that the sun is located at one of the foci of that ellipse. You also know what the eccentricity of the earth's orbit is, or you can easily look up that value in your Earth Science Reference Tables.

1. What is the numeric value of the eccentricity of the earth's orbit?

   ____

But what does that number mean, and what is the actual shape of the earth's orbit? Let's see.

The eccentricity (e), if you recall, is equal to d/L, where d is the distance between the foci along the major axis of an ellipse, and L is the length of that major axis. Essentially, the eccentricity is a ratio comparing the value of the two distances, d and L. By dividing the two values you compute the value of e but you have also mathematically calculated the relative value of d compared to L as though the value of L is equal to 1. Let's take a closer look at the earth's orbital eccentricity with this idea in mind.

The line below represents the major axis, L, of the earth's elliptical orbit with end points A and E, and the foci are points B and D. Point C is the center of the axis where the minor axis crosses the major axis at a right angle. Line segment AB = Line segment DE and Line segment BC = Line segment CD.

Because BC + CD = d (the distance between the foci) *and* if we let X = AB = DE, *then* L (the length of the major axis) = X + d + X = 2X + d

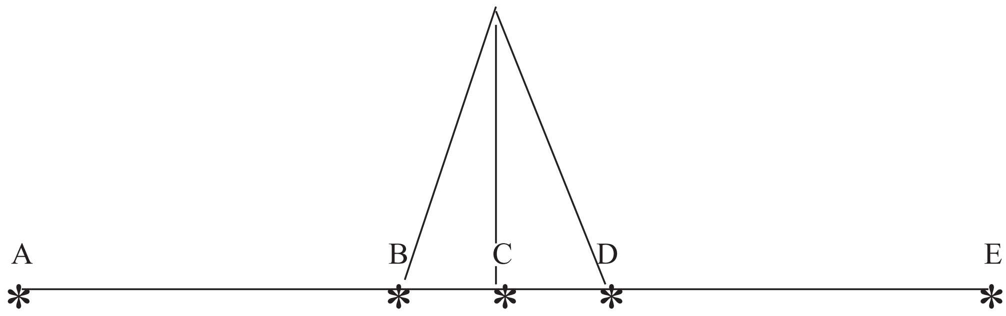
2. But d has a value (see Question 1 above). If we substitute that value in the equation, we have:

   L = 2X + ____________

3. And since the relative value of L is 1 (from our discussion above), then we have:

   1 = 2X + ____________

4. Solve this equation for the value of X in the box below (to four decimal places).



[---------------X----------------]---------d----------[----------------X----------------]

5. If, for the purposes of our model, we assume that point D is the location of the sun, the distance along the major axis from point A to point D is equal to X + *d* which in numbers equals __________________.
6. Assume that point B is the location of the sun. If so, this means that the earth is closest to the sun at point A in its orbit. This earth position is called: ________________________ and, when earth is at Point E, its position is called: ________________________.

But, what is the length of the minor axis that passes through point C perpendicular to *L*? Can we calculate that distance? Of course!

7. Because of the way ellipses are usually constructed using two pins and a fixed-length loop of string, we know that the perimeter of triangle FBD is also equal to what other distance in our model of the earth's orbit shown above? ________________________ (in letters) which is equal to what numerical values? ___________________________

(Don't be fooled by the lengths of the lines in the drawing above, since they are not drawn to scale.)

8. We also know from Pythagoras that (BF)^2 = (BC)^2 + (CF)^2 (because triangle FBC is a right triangle). If we substitute the values BF and BC into this equation, we can determine the length of CF which is one-half the **length of the minor axis**. Neatly show your work in the box below, even if you use your calculator to do most of the computations.

9. In conclusion, in the model above:

(1) The distance along the major axis from point C to the earth's orbit = ______________.
(2) The distance along the minor axis from point C to the earth's orbit = ______________.
(3) Therefore, how would you describe the shape of the earth's orbit?

____