Solar Education for NY
SchoolPower ...Naturally

THE SUN: EARTH'S EXTERNAL HEAT ENGINE
Part 2 of the Astronomy Model
SPN LESSON #33

TEACHER INFORMATION

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

LESSON OVERVIEW
In this lesson, students work with the variables that control 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 Earth. Students typically overestimate the importance of these variables in controlling heat gain by Earth.
- In Part 2, a scale model of Earth's orbit is mathematically modeled and evaluated, locations of Earth on that orbit are determined, and a model of Earth is used to study the effect of latitude on the availability of sunlight energy at Earth's surface. Also, models of Earth are used to measure sunlight angles at solar noon and to compare length of daylight for various latitudes at the solstices and equinoxes.

GRADE-LEVEL APPROPRIATENESS
This Physical Setting, Level III lesson is intended for students in grades 8–12 who are enrolled in Regents Earth Science.

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 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: 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 Earth’s surface. This occurs both through the dilution of incoming sunlight, which is spread over larger areas of 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 RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

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 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.

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ACTIVITY

This lesson is not adapted from another source.

BACKGROUND INFORMATION

The orbit of 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 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 = 1Btu) of heat received by one square centimeter of surface.

REFERENCES FOR BACKGROUND INFORMATION

Strahler, Arthur. *The Earth Sciences*, Harper & Row, 1963.
This book in any of its many editions is an invaluable reference.

Any of several Earth science texts and review books will be helpful.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

Listed below are the Physical Setting/Earth Science core understandings addressed in this activity.

Standard 1—Analysis, Inquiry, and Design: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematical Analysis Key Idea 1: Abstraction and symbolic representation are used to communicate mathematically.

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions.

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems.

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

Standard 4—Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 1: The Earth and celestial phenomena can be described by principles of relative motion and perspective.

1.1a: Most objects in the solar system are in regular and predictable motion.

- These motions explain such phenomena as the day, the year, seasons, phases of the moon, eclipses, and tides.
- Gravity influences the motions of celestial objects. The force of gravity between two objects in the universe depends on their masses and the distance between them.

1.1b: Nine planets move around the Sun in nearly circular orbits.

- The orbit of each planet is an ellipse with the Sun located at one of the foci.
- Earth is orbited by one moon and many artificial satellites.

1.1c: Earth's coordinate system of latitude and longitude, with the equator and prime meridian as reference lines, is based upon Earth's rotation and our observation of the Sun and stars.

1.1d: Earth rotates on an imaginary axis at a rate of 15 degrees per hour. To people on Earth, this turning of the planet makes it seem as though the Sun, the moon, and the stars are moving around Earth once a day. Rotation provides a basis for our system of local time; meridians of longitude are the basis for time zones.

1.1f: Earth's changing position with regard to the Sun and the moon has noticeable effects.

- Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris.
- During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather.

Standard 6—Interconnectedness: Common Themes: Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

Key Idea 3: The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems.

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www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Bill Peruzzi at billperuz@aol.com

(STUDENT HANDOUT SECTION FOLLOWS)

Name ___________________________________

Date _____________________________________

THE SUN: 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: Earth's Orbit.
Step 2: On your desktop, construct a model of 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. Since it is essentially a circle, the circumference = pi times the diameter.

The circumference is _______________________.

Although the speed of 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. Since our model Earth will travel in a counterclockwise direction around its orbit, and since 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:

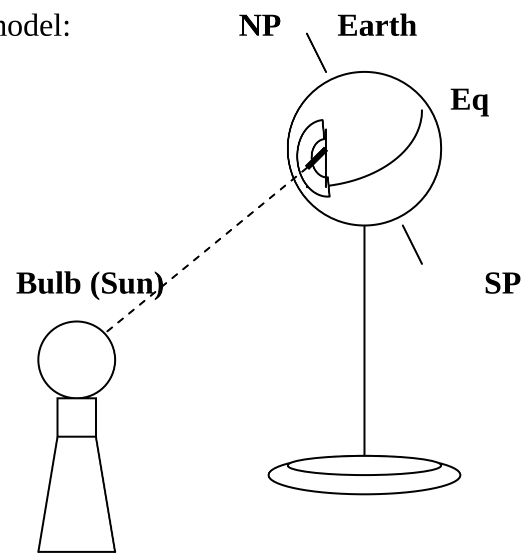
You have three tasks to perform on this portion of the lab exercise:

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 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? ____
____

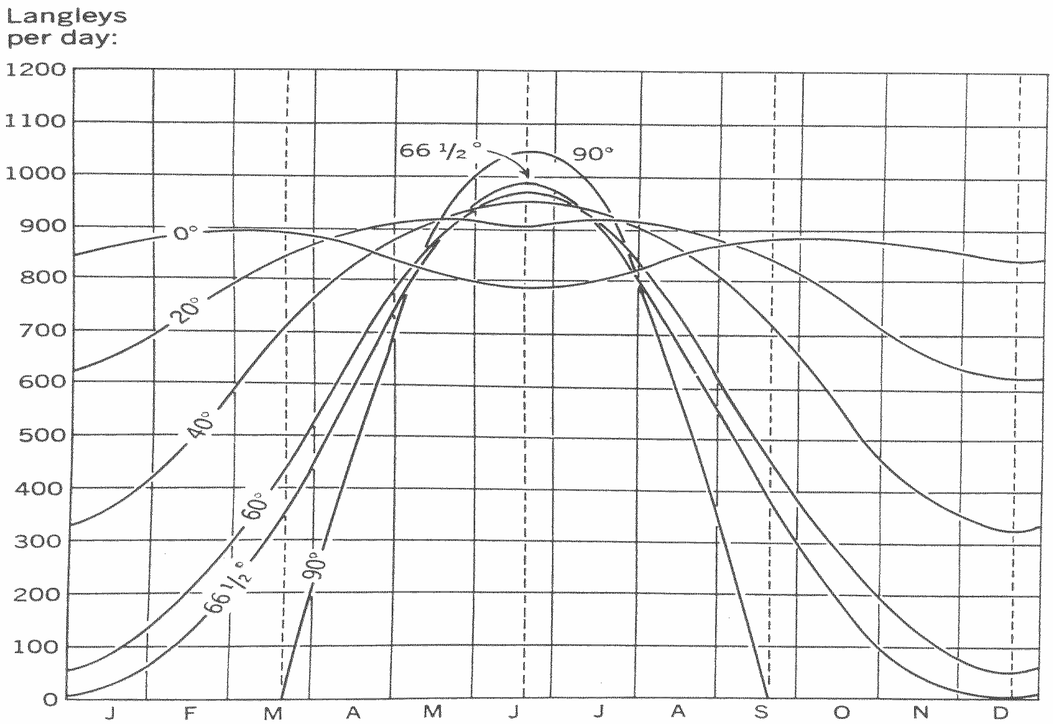


FIGURE 1 *Annual variation in daily insolation at selected latitudes in the Northern Hemisphere. (Data from Smithsonian Institution, Washington, D.C.)*

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?

____

____

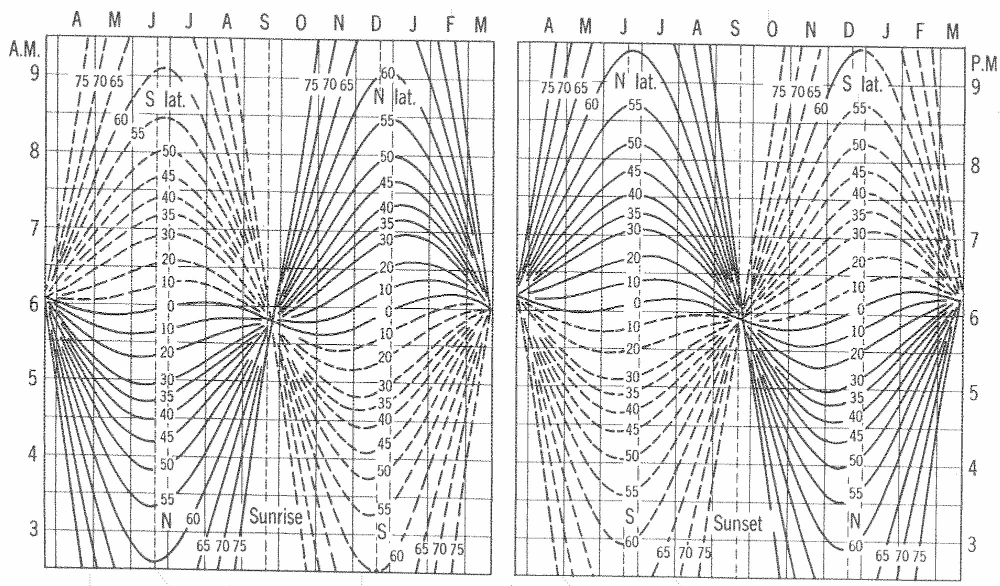


FIGURE 2 *Sunset-sunrise diagram. [Simplified from U.S. Navy Oceanographic Office Publication No. 5175. From A. N. Strahler (1960), Physical Geography, New York, John Wiley & Sons.]*

Name ______________________________

Date ______________________________

Worksheet 1: 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 Earth around the Sun. You know that the orbit of 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 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 Earth's orbit?

   ____

But what does that number mean, and what is the actual shape of 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 Earth's orbital eccentricity with this idea in mind.

The line below represents the major axis, *L*, of 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.

Since 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*

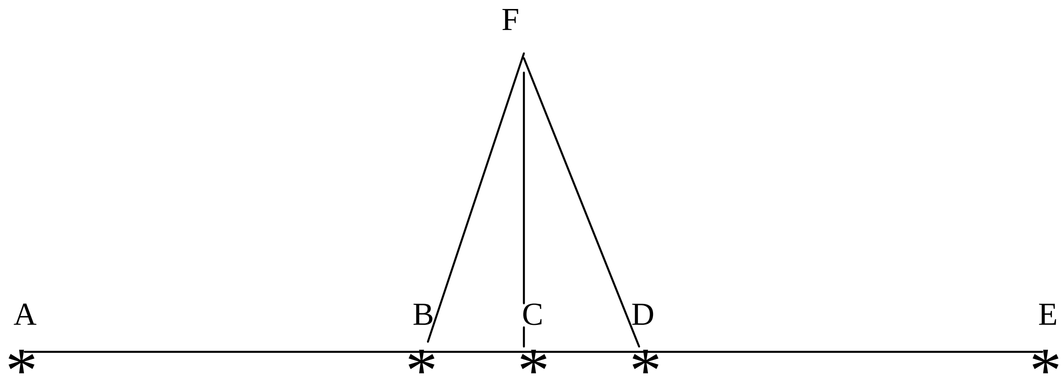
2. But *d* has a value (see question 1 above). If we substitute that value in the equation, we have:

   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 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 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 (since 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 Earth's orbit = _________________.
(2) The distance along the minor axis from point C to Earth's orbit = ________________.
(3) Therefore, how would you describe the shape of Earth's orbit?
____