Activity 2

Energy Transport in the Sun

Purpose

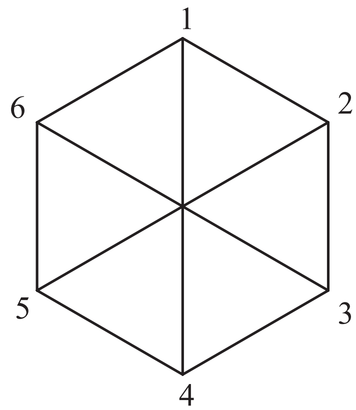
This is a 2-D demonstration of how a photon—a small bundle of light energy—might move in its journey from the interior to the surface of the Sun. Creative teachers might modify this into a game for several players that includes questions about the Sun as levels are reached, etc. Be imaginative!

Materials

1 six-sided die
1 pencil
1 sheet of isometric graph paper (example given in this section)
1 piece of corrugated cardboard the size of the graph paper
1 straight pin
1 drawing compass

Procedures

1. Find the center of the isometric graph paper (marked with an "O") and call it the center of the Sun.
2. Note that 6 lines radiate from this point to 6 new points, and so on, over the page.
3. To make keeping track a little easier, draw a series of circles at every 2 or 3 intersection points out to the twelfth circle. Call the outer circle the solar surface.
4. Assign the directions of the six lines radiating from a point to the values 1–6 as shown. The values can be in any arrangement you choose, but must be used consistently throughout this entire exercise.



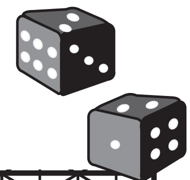
An example of numbering the directions of the hexagon.

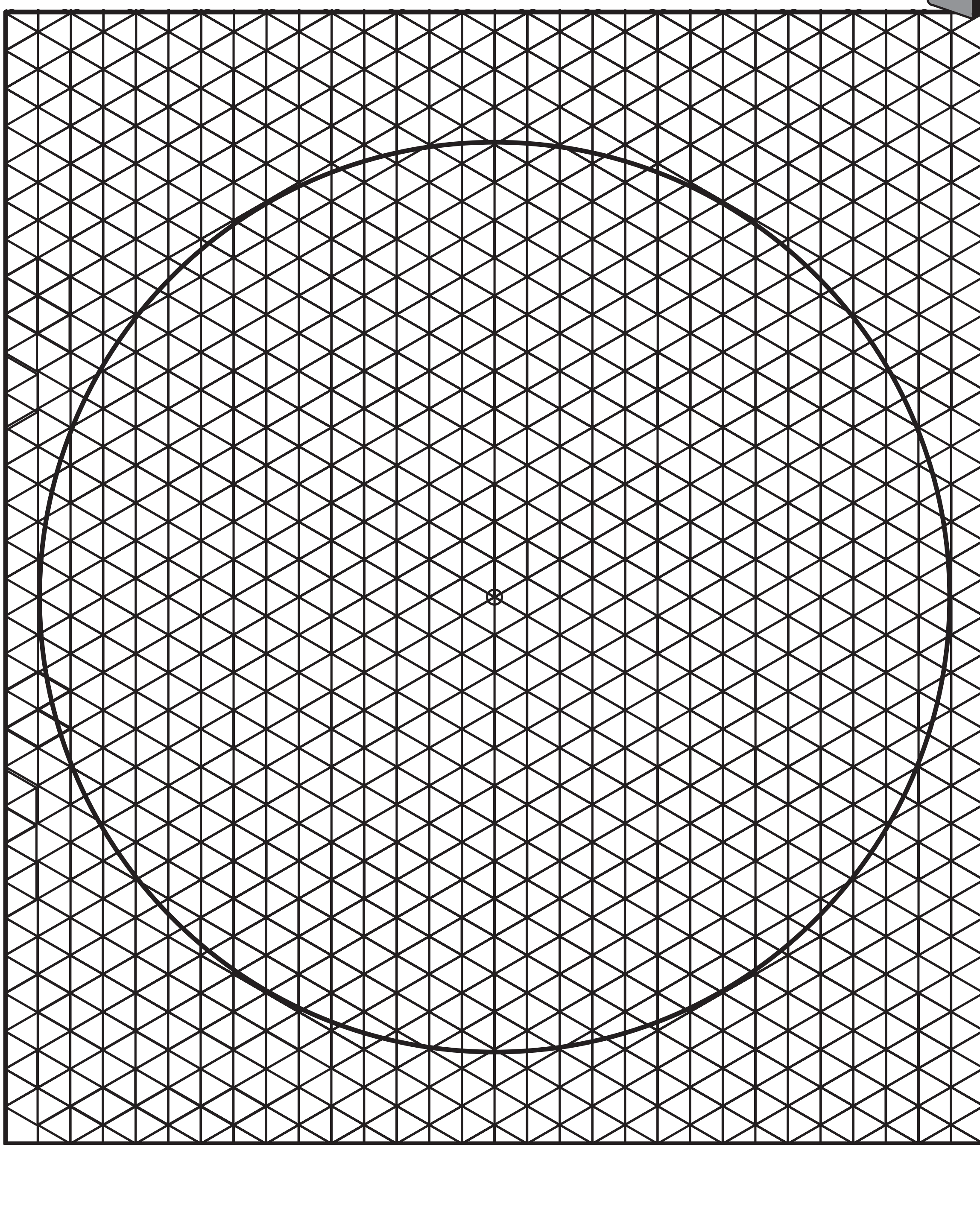
5. Starting at the center, roll the die and move 1 unit in the direction indicated. From this new point roll again and move 1 unit in the direction indicated. Continue until the surface of the sun is reached. Keep track of the total number of rolls needed to reach the edge of the sun.
6. Computer-oriented students may want to write a computer program to simulate the photon's movement. Use the random number generator to generate values 1–6 to simulate rolls of the die, and a matrix or array to keep track of position. A graphics display could also be incorporated into the program.
7. Have a group of students (class) each do this exercise and tabulate the average number of trials it takes to reach each radius. Then compare the averages with the value of the radius squared, i.e. at r=4, compare trials to 16.
8. A game idea might be as follows:
   a. 3 or 4 students start with a pin at "O"
   b. Each takes turns rolling the die and moving the pin to a new location
   c. At each even radius line, (2, 4, 6...), a question card is drawn from a deck of index cards, prepared by the teacher or class with questions about the sun).
   d. If the question is answered correctly, the student can take a "quantum leap" to an odd radius (3, 5, 7...).
   e. If they answer incorrectly, a turn is lost.
   f. The winner is the first to reach the solar surface. Give each winner a package of sunflower seeds or a pack of Starburst® candy.
9. Based on the game idea above, try different grid arrangements to match the different dice available at hobby and game stores (especially "Dungeons and Dragons™" games).

   Draw from different question decks based on odd or even rolls. For older students, one deck might be for calculation problems, the other for verbal questions.

Photons take a collision-filled journey to the surface of the Sun. The gamma photons are absorbed and re-emitted repeatedly in the radiative core of the Sun. The energy produced in the core may take as long as 50 million years to work its way out!

See if you can work your way out using the dice to decide your path.





For the Teacher

The mathematics that describes the photons' movement that carries the energy from the solar interior to the surface is based on probability and statistics. Even though the exercise described is 2-D, the actual case of 3-D photon movement in the sun follows the same mathematical theory and can be shown to produce the same result.

To show how the process works, a 1-D model will be described. Examine a line with the starting point at 0 and each jump, either backward or forward, is called j (+j or –j). After a lage number of jumps, n, the average distance X_n should be zero,

or

$$\frac{\sum X_n}{n} = 0$$

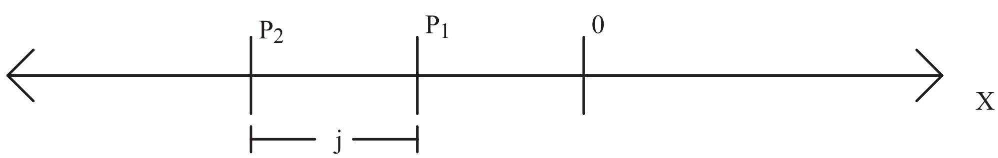
The standard deviation,

$$\sigma$$

where

$$\sigma_n^2 = \frac{\sum X_n^2}{n}$$

will give the statistical position of the photon from 0 after n jumps.



Then if at (n–1) jumps, the point P_1 is the location of the photon, P_2 is the location after one more jump j.

The distance is then given by:

$$X_n = X_{n-1} \pm j.$$

Thus:

$$\sigma_n^2 = \frac{\sum X_n^2}{n} = \frac{\sum X_{n-1}^2}{n} \pm \frac{2 \times j \times \sum X_{n-1}}{n} + \frac{n \times j^2}{n}$$

But,

$$\frac{\sum X_{n-1}}{n} = 0$$

Therefore:

$$\sigma_n^2 = \sigma_{n-1}^2 + j^2$$

This is a recursion formula such that

$$\sigma_{n-1}^2 = \sigma_{n-2}^2 + j^2$$

Then :

$$\sigma_n^2 = \sigma_{n-2}^2 + 2 \times j^2 = \sigma_1^2 + (n-1) \times j^2$$

However,

$$\sigma_1^2 = j^2$$

Therefore:

$$\sigma_n^2 = n \times j^2$$

This is the squared relationship that you should see in the average number of rolls to each radius.

It has been determined that for the sun, each photon jump is about 1cm and the radius of the sun is about

$$7 \times 10^{10}\ cm$$

So,

$$\sigma_n = 7 \times 10^{10}\ cm \quad \textit{for 1 photon to reach the surface}$$

Substituting these values in

$$\sigma_n^2 = n \times j^2$$

gives

$$\left(7 \times 10^{10}\right)^2 = n \times 1^2$$

$$n = 5 \times 10^{21}\ jumps$$

The speed of light is

$$3 \times 10^8\ \frac{m}{s}$$

and assuming little or no time for the photon to wait at each jump point, then

$$5 \times 10^{21}\ jumps \times \frac{.01\ m}{1\ jump} \times \frac{1\ s}{3 \times 10^8\ m} = \frac{5}{3} \times 10^{11}\ seconds$$

for the photon to reach the sun's surface.

Converting this to years:

$$\frac{5}{3} \times 10^{11}\ seconds \times \frac{1\ h}{3600\ s} \times \frac{1\ d}{24\ h} \times \frac{1\ y}{365\ d} = 5300\ years$$

Even though this is a very long time for 1 photon, the process of being absorbed and remitted at each jump adds considerable time to the process—up to 50 million years.