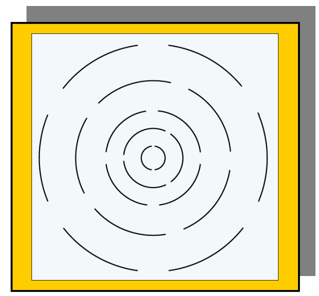
The Sun and Solar Wind:
A Search for the Beginning

Photons in the Radiative Zone: Which Way is Out? An A-Maz-ing Model

TEACHER GUIDE

BACKGROUND INFORMATION



Students try to work their way out of a circular maze, thereby modeling the movement of a photon as it travels through the **radiative zone** of the sun. Classroom discussion after they complete the activity is focused on the Standard Solar Model and its importance in further scientific studies of the sun.

STANDARDS ADDRESSED

Grades 5-8

Science As Inquiry
- Understandings about scientific inquiry

Science and Technology
- Understandings about science and technology

Physical Science
- Properties and changes of properties in matter
- Transfer of energy

History and Nature of Science
- Science as a human endeavor
- Nature of science and scientific knowledge
- History of science and historical perspectives

Grades 9-12

Science As Inquiry
- Understandings about scientific inquiry

Science and Technology
- Understandings about science and technology

Earth and Space Science
- The origin and evolution of the Earth system

Physical Science
- Properties and changes of properties in matter
- Transfer of energy

History and Nature of Science
- Science as a human endeavor
- Nature of science and scientific knowledge
- History of science and historical perspectives

MATERIALS

For each student (or pair of students)
- Copy of Student Activity "Photons in the Radiative Zone: Which Way is Out?"
- A protractor
- A straight edge
- Copy of "Standard Model of the Sun"
- Copy of Student Text "Models in Science"

PROCEDURE

1. Before class, make copies of the Student Activity, "Photons in the Radiative Zone: Which Way is Out?" If you have not already done so, makes copies of the Handout "Standard Model of the Sun" and Student Text, "Models in Science".

2. Group the class into pairs. Hand the first two pages (the instructions and the maze) of Student Activity "Photons in the Radiative Zone: Which Way is Out?" to each student or each pair of students. Instruct them to complete the maze in pencil, since they may wish to make more than one try at the problem.

   Tell them to follow the instructions at the top of the page. They should draw only straight lines until they run into a barrier. At this point, they should use a protractor to determine the angle at which the line away from the barrier should be drawn. The angle of reflection should equal the angle of incidence. Again, the line of reflection should be drawn using a straight edge. The goal of the assignment is to find a way out of the maze.

> **Alternative Strategy Tips**
>
> Prepare "black boxes" for each group of students by placing a small, unbreakable object in a box and sealing it. Using their senses, students observe the object, determining whether or not:
> a) it is heavy,
> b) it rolls or slides,
> c) it has an odor, etc.
> They must decide what is in the box on the basis of their observations.
>
> Electric circuit black boxes can also be constructed with light bulbs mounted on top. Students are challenged to determine the types of circuits connecting the bulbs.

3. Ask one student in each group to record the problem-solving processes they used to work their way out of the maze. They should record whether or not the process was successful and why it was or was not.

   They may begin to wonder whether or not it is possible to work their way out of the maze. Assure them that there are a number of ways to do this.

4. When they have worked their way out of the maze (or you have called time), bring them back together for a general class discussion. Have each group report to the class the successful and unsuccessful problem-solving processes they tried as they completed the assignment.

5. Tell students to review the Student Text "Modeling the Sun" before the next class period.

6. Review the characteristics and the purpose of a good scientific model from the previous class discussion on models and follow this with questions similar to the following:
   a. In the maze model that you worked on
      i. What do the holes model?
      ii. What do the lines model?
      iii. Why is the maze circular?
      iv. In what way(s) is the maze a good model for the path of a photon in the radiative zone of the sun?
      v. In what way(s) is this model not accurate?

> **Alternative Strategy Tips**
>
> Have students do the following calculations:
>
> 1. How long would it take a photon, starting at the center of the sun's core and traveling at the speed of light, to reach the sun's surface, a distance of 7 x 10^5 Km, if it did not collide with electrons or any other particles?
>
> 2. Using a ratio, compare the length of time a proton *actually* stays in the sun compared to the direct route time you calculated in #1 above.

b. Critique this model of the sun's radiative zone. Was it a good model, an adequate model, or a poor model? Defend your rating of the model.

c. Based on the students' list of criteria, devise a list of criteria for a good model of photon movement in the sun's radiative zone.

d. Divide the class into teams of four students to design another, perhaps better, model for the path of a photon in the radiative zone of the sun.

e. Have each team make an illustrated oral presentation of its model. The presentations can be evaluated either by other class members or by you, using the criteria developed by the class.

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STUDENT ACTIVITY

You will work on this assignment in pairs. One student in each group should record the problem-solving processes used to complete the assignment. Record whether or not the process was successful and why it was or was not. Be prepared to share these notes with other members of the class

You may want to complete the maze in pencil, since you may wish to make more than one try at the problem.

The goal of this assignment is to find a way out of the maze, following these instructions.

Names of students in the team: ______________________________

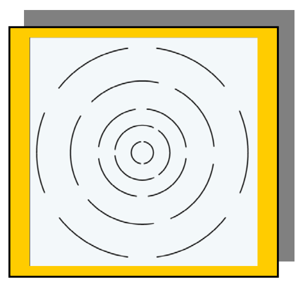
____

1. Note the time started on line b.

Exit time: a)____________

Time started: b)____________

Time required: c)____________



2. Start at the center of the maze. Using a straight edge, draw a line out from the center circle until it intersects a barrier.

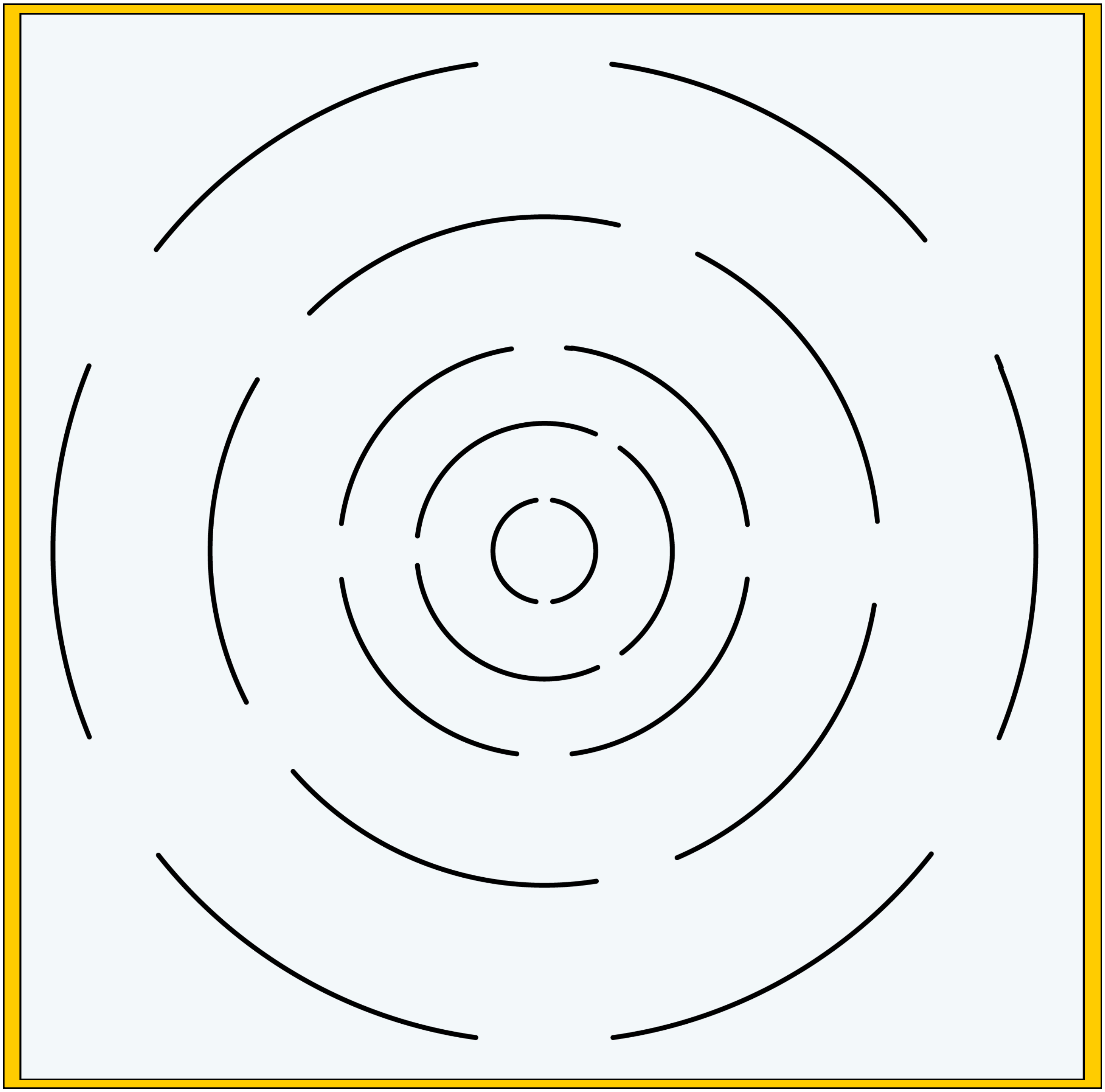
3. Use a protractor to determine the angle at which the line intersects the barrier.

4. Measure an equal angle in the opposite direction of the intersection. Draw a straight line at this angle until it intersects another barrier.

5. Continue this process until the line goes through an opening in the outside line.

6. Record the time on the line labeled "exit time" and calculate the time required to complete the assignment.

Figure 1



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STUDENT TEXT

How long did it take you to find your way out of the maze? A few minutes? An hour? Can you imagine a maze that takes a million years to exit? Some of the photons that are part of solar wind spent at least that long finding their way out of the radiative zone of the sun. Where did these photons and other particles come from? What happens to them when they finally exit the sun's structure? Scientists will be searching for potential answers to those questions and others when they analyze the Genesis solar samples.

Refer to the handout, "Standard Model of the Sun," as you follow photons through their trip to the sun's surface, as envisioned in the Standard Solar Model.

Photons in the Core

As you learned in "The Invisible Fire," a hot brew of protons, neutrons, nuclei, and free electrons is produced in the nuclear inferno of the sun's core. Tiny packets of energy called photons, the particle component of electromagnetic radiation, start on an incredible journey that ultimately results in their being spewed forth into space.

In the extremely dense core, photons of short wavelength, called high-energy gamma rays (γ), lose energy as they collide with electrons (not with walls!) to form longer wavelength and less energetic x-ray photons. These photons follow a long, torturous route as they work their way to the surface of the sun.

Photons in the Radiative Zone

Once the photons escape from the core, they travel outward in the **radiative zone**. Deep in the radiative zone, the photons collide with plasma particles and change direction in random ways. Each photon may travel only a few millimeters before it suffers another collision and is set off in a different direction. Nevertheless, the photons continue to work their way toward the surface by meandering in zig-zag fashion toward regions of lower temperature and pressure. The time that it takes for them to complete their journey to the surface is measured in the millions of years, which is an incredible fact given that the photons travel at the speed of light! To put it in more personal terms, the sunlight that gave you your tan last summer resulted from a nuclear reaction that took place perhaps 1,000,000 years ago deep within the core of the sun.

Are We There Yet?

Some of the electrons in the radiative zone are captured by helium nuclei to form ionized helium atoms. The radiative zone, which is packed with ionized hydrogen and helium atoms, extends from the core of the sun about 70% of the distance to the surface. This mixture of ionized hot gases and electrons is called a **plasma**, a fourth state of matter. While moving through the radiative zone, the photons encounter less and less dense materials. Two-thirds of the way through, the density is about the same as that of air, and at the edge of the zone, the density is thought to be around 0.1 g/cm^3.

We're Still in the Dark

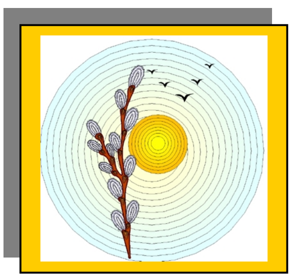
Until this time, the energy produced is in the high energy spectrum beyond that of visible light. The collisions suffered by the photons rob them of part of their energy, and consequently their wavelengths gradually become longer and longer as they move toward the convection zone. Ultimately wavelengths corresponding to visible light are reached.

The Convection Zone: The Mystery Layer

When the photons arrive at the convection layer, 150,000 km below the sun's surface, the nuclei are able to hold on to electrons, and neutral atoms and ions are formed. And photon energies have been degraded to the point that gaseous atoms and ions absorb the energy of the photons and hold it, rather than having it bounce off (or be absorbed and re-radiated). These atoms effectively block the outward flow of radiative energy and the energy absorbed by the atoms makes them enormously hot.

At that point the convection currents take over and carry the sun's energy to the photosphere on seething rivers of hot gases. Although it may have taken the photons a million years to reach the convection zone, the energy they deliver rises through the entire convention zone in about three months. All the energy emitted at the surface of the sun is transported there by convection.

The Photosphere: Ah! Light At Last!



The photosphere, at the top of the convection zone, is the visible bright surface of the sun. Here the gaseous atoms no longer block radiative flow. As the hot atoms cool, they release their excess energy once again as photons that stream unimpeded into space and ultimately provide support for life on Earth.

[For further description of the sun, read "The Structured Sun" in Appendix C. To review how the Standard Solar Model was developed, refer to the Student Text "Models in Science."]