Solar Energy Flow Student Guide

In this student guide, we will explore how the flow of energy occurs through the Sun. Specifically with a focus on photons produced in the Sun’s core. Use of the program and the following background information may be necessary for the completion of this guide.

**Background**

Stellar nucleosynthesis is the process by which new elements are formed inside stars. This process involves the fusion of lighter atomic nuclei into heavier ones. In the course of these reactions, energy is released in the form of light and heat.

To understand how stellar nucleosynthesis produces light, we need to look at the fusion reactions that take place inside stars. These reactions are driven by the high temperatures and pressures that exist in the stellar core. In the core of a star, hydrogen atoms are compressed and heated until they fuse together to form helium atoms. This reaction releases a tremendous amount of energy in the form of light and heat.

As the star evolves, the fusion reactions continue, producing heavier and heavier elements. In stars like our Sun, helium atoms are fused together to form carbon and oxygen, which also release energy in the form of light and heat. This process continues, with increasingly heavier elements being formed until the star reaches the end of its life.

For an example, the following describes a process by which 4 hydrogen nuclei fuse together to form helium and other byproducts:

However, the light that is produced in the core doesn't immediately escape the star. Instead, it takes a very long time to reach the surface of the star and then travel through space to reach us. The light produced through fusion reactions in a star's core is delayed from escaping the star because it interacts with the dense plasma of charged particles that surround it, which scatters and absorbs the photons. Each time a photon is absorbed and re-emitted, it loses a little bit of energy and changes direction.

This process can happen many times before a photon finally makes it to the surface of the star. As the density of the matter surrounding the core decreases towards the outer layers of the star, the scattering and absorption become less severe, allowing the photons to finally escape into space and reach us.

This process of absorption and re-emission causes photons produced in the core to not reach the star’s surface for a period measured in either thousands or millions of years. In contrast to this, the light itself has a speed such that it only takes about 8 minutes for light escaping the Sun’s surface to reach the Earth.

**Student Questions**

Open the program, and begin working through the various options to answer the following questions and gather the required information. Also ignore the “pygame” window if ran using the .exe file, as I’m not sure how to avoid that right now. In case of issues, the program can also be closed by pressing Q or the Esc key while the window is active.

**Q1.** Choose any option on the simulator, and see how the particles (represented by red dots) move about. How would you describe this motion? Is there a word for it, and do you know why the particles move this way?

**Q2**. Now choose the “tiny star” option, and pay attention to the indicator on top to measure the number of total movements for all 10 photons in the simulation. When the photons reach the edge of the star (represented as a circle), they should disappear. How many total movements take place before all the photons escape? What is the average number of steps required for a single photon?

**Q3**. Let’s now examine the different sizes of star, and see how size affects the time it takes for a photon to escape. In the table below, repeat a few runs for each different size of star but with the same amount of photons. Keep in mind the size of each star is given in pixels.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Tiny star | Small star | Medium star | Large star |
| Run 1 |  |  |  |  |
| Run 2 |  |  |  |  |
| Run 3 |  |  |  |  |
| Run 4 |  |  |  |  |
| Run 5 |  |  |  |  |
| Average |  |  |  |  |
| Average/photon |  |  |  |  |

*Table 1.*

**Q4.** Using the data from the previous table, what can you conclude about how the thickness of a star affects the amount of movements it takes to escape the star? Can you word it in a mathematical sense?

**Q5.** Now select the option for a medium star with 100 particles, and calculate how many movements it takes an average photon to escape. How does this average compare to the average you previously calculated in Table 1?

**Q6.** The speed of light is approximately 300,000,000 m/s, or 3 x 108 m/s, and the radius of the Sun is approximately 695,700,000 m. Using this information, calculate how long it would take a photon produced within the Sun’s core to reach the edge of its surface if it did not interact with its environment. How does this value compare to the time it actually takes for a photon to escape from the core?

**Q7.** In the background information, an example of what is called proton-proton chain fusion was given. This process produces photons as gamma rays, but the Sun only emits gamma rays during extreme solar events such as powerful solar flares. So if the Sun is producing gamma rays, why do we not normally detect them?

**Q8.** The sun emits a spectrum of light, which very roughly correlates to the emission spectra of a blackbody. But the light within the core is produced through nucleosynthesis, resulting in specific wavelengths of light dependent on the reaction taking place. How does the light produced ultimately result in a range of light emitted at the surface?