# Where Do Stars Get Their Energy?

## Course Outcomes Met

1. Communicate scientific issues effectively in oral and written form;
2. Effectively collect, analyze and present data and correctly construct and interpret charts, graphs and tables to draw scientific conclusions;
3. Apply the fundamental concepts and methodologies of physics and/or chemistry to investigate a scientific theme.

Tools used in this activity:

Printed cards for each step of the p-p and CNO fusion reactions

## A. The Proton-Proton Chain

Follow the instructions on the cards. As you go along keep track of how many helium nuclei, photons, and neutrinos you produce. Also record how many times you had to try at each step before you got to move on to the next.

1. The core of the Sun is a highly compressed gas of hydrogen and helium nuclei. They experience high velocity collisions with each other billions of time each second. If that is true, why doesn’t all the hydrogen fuse all at once and the Sun go off like a giant camera flash and then die? In short, why do we still have a Sun?

2. How many 1H went into the reaction chain? How many 4He came out? How many photons? How many neutrinos?

3. Can you explain why, on Earth and elsewhere in the universe, 4He and 7Li are far more common than 3He and 8Li respectively, even though those isotopes are also stable.

4. There actually is a p-p III branch but it is extremely rare, happening only 0.3% of the time. In this branch, 7Be absorbs a proton to become 8B (Boron) and emits a photon. 8B then β+ decays to become 8Be, emitting a positron and a neutrino. As usual, the positron quickly finds an electron to annihilate with and create two photons. After about 8 seconds, 8Be spontaneously fissions to become two 4He nuclei. Looking at this chain of events, in comparison to what you have already seen in the other chains, can you see the bottleneck that makes it unlikely to occur?

5. You may have noticed that the actual half life for going from 2H to 2He is about a billion years. To match this probability using dice rolls, we would need about 150 million dice and you would have to roll them over and over until they all come up ones. If that reaction happens so rarely, how does the Sun generate any energy at all?

**Check your results with your instructor at this point**

## B. CNO Cycle

Follow the instructions on the cards. As you go along keep track of how many helium nuclei, photons, and neutrinos you produce. Also record how many times you had to try at each step before you got to move on to the next. If you end up back where you started, then you can stop. Make a copy of the element table and use numbered arrows to show the sequence of reactions you experienced. Label each arrow with the reaction type (fusion or decay).

1. Why is it a cycle and not a chain?

2. Compare the number of photons and neutrinos you made here to those from the p-p chain.

3. Consider the full loop that you made. What has been created or destroyed during that loop? Is the carbon consumed by this reaction like the hydrogen was in the p-p chain?

4. Compare your experience to other students. How many different CNO cycles did you discover as a class? How do they differ?

5. Why did you get stuck at 14O and 15O?

6. Like charges repel. The bigger either of the charges are, the stronger the repulsion. So to make nuclei with a larger number of charges fuse requires a higher compression or a higher temperature or both. Considering this, in small stars like the Sun, which of these two fusion processes would most likely be the dominant one? How about in much more massive stars?

7. Stars are just big balls of hot gas. Their gravitational field should make them shrink. But there is something else going on. It isn’t just gas, but a gas of electrically charged particles (a plasma). Photons interact very strongly with electric charges and exert a force on them. This is called *radiation pressure.* So a star maintains a stable size when radiation pressure pushing out exactly balances gravity pulling inward. Looking at your results, how does the presence of the CNO cycle in large stars help them maintain this balance?

**Check your results with your instructor at this point**