

Fusion in the Sun: the Proton-Proton Chain

When two nuclei in the center of a star collide at high velocity, they can fuse together to form a single larger nucleus.

If the mass of the new nucleus is less than the mass of the colliding nuclei, the mass difference is released into the star as energy. Fusion in the energy behind starlight.

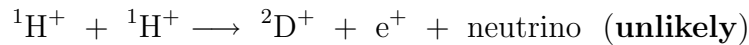
The energy appears as some combination of **antielectrons** (which quickly collide with electrons and turn into photons), **photons**, **kinetic energy** (both of which provide energy to help keep the core of the Sun hot), or **neutrinos** (which escape the Sun immediately).

In the Sun, a new helium nucleus is formed by fusing together four hydrogen nuclei in several stages. Today you will work out the different pathways by which this can happen.

Figure 1 : Four isotopes important to nuclear fusion in the Sun: hydrogen, heavy hydrogen (deuterium), light helium (helium-3), and helium. Each isotope is described by a letter, a small number giving the total number of protons or neutrons, and one or more plus signs. Each plus sign indicates one unit of positive electric charge.

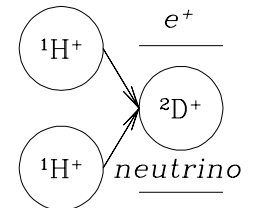
Hydrogen	Deuterium	Helium-3	Helium
${}^1\text{H}^+$	${}^2\text{D}^+$	${}^3\text{He}^{++}$	${}^4\text{He}^{++}$
$\textcircled{\text{p}}$	$\begin{matrix} \textcircled{\text{p}} \\ \textcircled{\text{n}} \end{matrix}$	$\begin{matrix} \textcircled{\text{p}} & \textcircled{\text{p}} \\ & \textcircled{\text{n}} \end{matrix}$	$\begin{matrix} \textcircled{\text{p}} & \textcircled{\text{p}} \\ \textcircled{\text{n}} & \textcircled{\text{n}} \end{matrix}$
1 proton	1 proton 1 neutron	2 protons 1 neutron	2 protons 2 neutrons

Two hydrogen nuclei can collide to produce a deuterium nucleus and byproducts (an antielectron, which has the symbol e^+ , and a neutrino), but that is not likely to occur every time such a collision happens. As a shorthand, we write:



The number of positive charges is the same on each side of the arrow (net electric charge is conserved), and if you add up the small numbers on each side of the arrow, they are equal.

Figure 2 : We can also draw this reaction as shown on the right. Each circle represents one nucleus. The arrows indicate that two ${}^1\text{H}^+$ nuclei collide and form one ${}^2\text{D}^+$ nucleus. Byproducts of the collision are written on the blank lines: in this case, an antielectron and a neutrino.



To work out how four ${}^1\text{H}^+$ fuse into one ${}^4\text{He}^{++}$, use this list of the important fusion reactions in the Sun and the chances they will happen in a single collision:

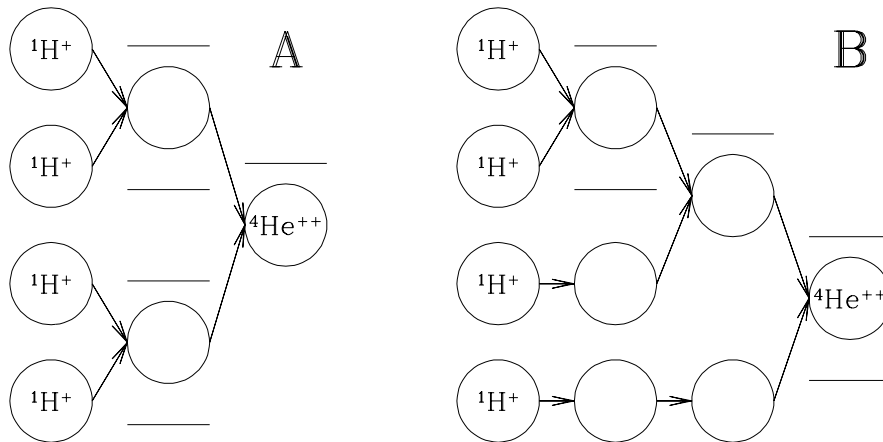
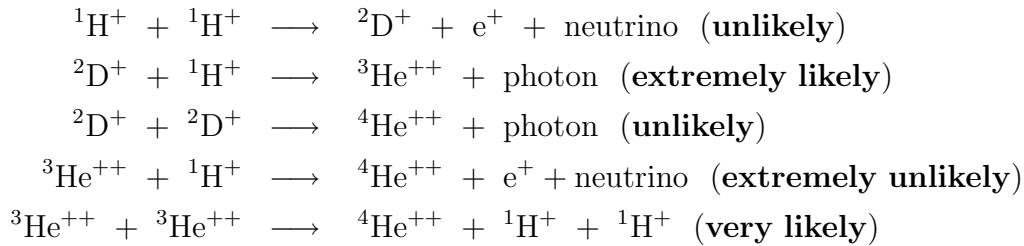


Figure 3 : You can now fill in the blank circles and the blank lines in the three pathways to ${}^4\text{He}^{++}$ shown.

Fusion Pathway Rules:

- I) The number in a circle must equal the sum of the numbers going into it.
- II) The positive charge coming out of a collision must equal the positive charge going into it.
- III) Only the five reactions at the top of the page are important here.

Questions to Answer:

- 1) How many neutrinos are produced along with every ${}^4\text{He}^{++}$ nucleus in pathway A ____ ? B ____ ? C ____ ?
- 2) Which of the three pathways will be the most common one, and why? (Hint: ${}^1\text{H}^+$ is the most common nucleus.)

