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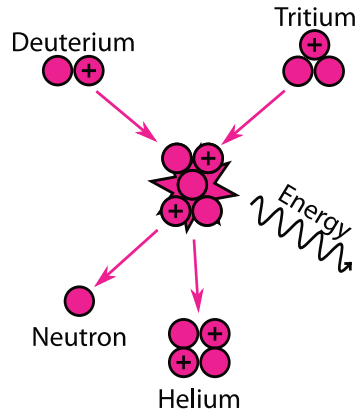
57 Fusion – The Process ♡

Nuclear fusion is the process by which two atomic nuclei combine to form a single atomic nucleus. If the two nuclei that go into a fusion reaction have an atomic number below 26 (the atomic number of iron), the nuclear reaction can release energy.



Atomic nuclei are positively charged. Like charges repel each other. The strength of the electrostatic repulsive force increases as the distance between the nuclei decreases. This force prevents the two nuclei getting close enough to fuse unless the nuclei are moving very fast. If the nuclei are moving very fast, the electrostatic repulsive force cannot stop two nuclei moving towards each other until it is too late; they are close enough to fuse, under the action of the strong nuclear force, and become a single nucleus. This barrier to nuclear fusion is called the Coulomb barrier.

Once the Coulomb barrier is breached, far more energy is released than the energy required to breach the Coulomb barrier in the first place.

In stars, atomic nuclei are given sufficient energy to breach the Coulomb barrier because the temperature in the star is so high. On Earth, experimental fusion reactor designs focus on energy-efficient ways of increasing the speed of the atomic nuclei and on novel methods for reducing the Coulomb barrier. To date, no fusion reactor on Earth has released energy at a self-sustaining rate for more than a fraction of a second.

The best atomic nuclei to use as a fuel in a fusion reactor are hydrogen, which has the fewest number of protons of any atomic nucleus. The Coulomb barrier can be more easily overcome by using isotopes of hydrogen that contain neutrons, such as deuterium (one proton, one neutron) and tritium (one proton, two neutrons).

Hydrogen is a readily available fuel because it is present in water, which covers approximately 70% of the Earth's surface.

57.1 When two hydrogen atoms fuse, what element is produced?

57.2 In the Sun, helium−4 atoms are produced. The only atomic nuclei that go into the reaction are hydrogen−1. The reaction has many stages, the last of which produces two protons and one helium−4 nucleus.

(a) How many nucleons are input into the reaction chain?

(b) All of these nucleons are initially protons, but some of them can transform into neutrons. How many protons transform into neutrons for each occurrence of this reaction chain?

(c) Each proton that transforms into a neutron emits a particle with positive charge. What is this particle called?

(d) What happens to the emitted particle in (c)?

57.3 At what temperature can nuclear fusion of hydrogen naturally occur?

57.4 In the early 1950s, the first nuclear fusion device was successfully tested. What was the purpose of this device?

57.5 Stars larger than the Sun involve another nuclear fusion chain, called the CNO cycle. What do the letters C, N and O stand for?

57.6 In what form is the energy released from a nuclear fusion reaction initially?

57.7 Explain why the mass of the Sun reduces by about $4\,000\,000$ tonnes per second. [See Q50.4d for luminosity.] 1 tonne = 1000 kg