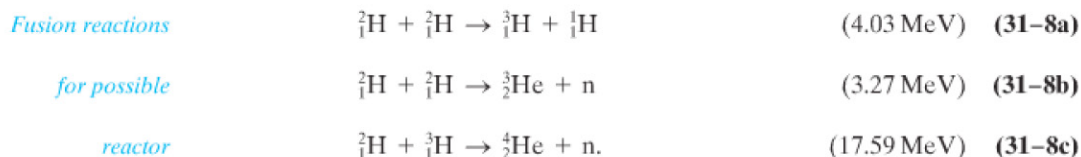## Possible Fusion Reactors

*Fusion reactor*   The possibility of utilizing the energy released in fusion to make a power reactor is very attractive. The fusion reactions most likely to succeed in a reactor involve the isotopes of hydrogen, $^2_1$H (deuterium) and $^3_1$H (tritium), and are as follows, with the energy released given in parentheses:

*Fusion reactions*
$$^2_1\text{H} + ^2_1\text{H} \rightarrow ^3_1\text{H} + ^1_1\text{H} \qquad\qquad (4.03\,\text{MeV}) \quad \textbf{(31–8a)}$$

*for possible*
$$^2_1\text{H} + ^2_1\text{H} \rightarrow ^3_2\text{He} + \text{n} \qquad\qquad (3.27\,\text{MeV}) \quad \textbf{(31–8b)}$$

*reactor*
$$^2_1\text{H} + ^3_1\text{H} \rightarrow ^4_2\text{He} + \text{n}. \qquad\qquad (17.59\,\text{MeV}) \quad \textbf{(31–8c)}$$

Comparing these energy yields with that for the fission of $^{235}_{92}$U, we can see that the energy released in fusion reactions can be greater for a given mass of fuel than in fission. Furthermore, as fuel, a fusion reactor could use deuterium, which is very plentiful in the water of the oceans (the natural abundance of $^2_1$H is 0.0115% on average, or about 1 g of deuterium per 80 L of water). The simple proton–proton reaction of Eq. 31–6a, which could use a much more plentiful source of fuel, $^1_1$H, has such a small probability of occurring that it cannot be considered a possibility on Earth.

Although a useful fusion reactor has not yet been achieved, considerable progress has been made in overcoming the inherent difficulties. The problems are associated with the fact that all nuclei have a positive charge and repel each other. However, if they can be brought close enough together so that the short-range attractive nuclear force can come into play, the latter can pull the nuclei together and fusion will occur. For the nuclei to get close enough together, they must have large kinetic energy to overcome the electric repulsion. High kinetic energies are easily attainable with particle accelerators (Chapter 32), but the number of particles involved is too small. To produce realistic amounts of energy, we must deal with matter in bulk, for which high kinetic energy means higher temperatures. Indeed, very high temperatures are required for fusion to occur, and fusion devices are often referred to as **thermonuclear devices**. The Sun and other stars are very hot, many millions of degrees, so the nuclei are moving fast enough for fusion to take place, and the energy released keeps the temperature high so that further fusion reactions can occur. The Sun and the stars represent huge self-sustaining thermonuclear reactors that stay together because of their great gravitational mass; but on Earth, containment of the fast-moving nuclei at the high temperatures and densities required has proven difficult.

It was realized after World War II that the temperature produced within a fission (or "atomic") bomb was close to $10^8$ K. This suggested that a fission bomb could be used to ignite a fusion bomb (popularly known as a thermonuclear or hydrogen bomb) to release the vast energy of fusion. The uncontrollable release of fusion energy in an H-bomb (in 1952) was relatively easy to obtain. But to realize usable energy from fusion at a slow and controlled rate turned out to be a serious challenge.

**EXAMPLE 31–9** ESTIMATE **Temperature needed for d–t fusion.** Estimate the temperature required for deuterium–tritium fusion (d–t) to occur.

**APPROACH** We assume the nuclei approach head-on, each with kinetic energy KE, and that the nuclear force comes into play when the distance between their centers equals the sum of their nuclear radii. The electrostatic potential energy (Section 17–5) of the two particles at this distance must equal the total kinetic energy of the two particles when far apart. The average kinetic energy is related to Kelvin temperature by Eq. 13–8.