11.7: Nuclear Fusion

As we saw in the preceding section, when the nuclei of heavy atoms split, energy is released. For light atoms, the opposite is true; when these nuclei combine (fuse together), energy is released. This is the process of nuclear fusion. Fusion of light elements, mostly hydrogen, is the force that powers energy release in the sun and in sun-like stars. Imagine the sun as a huge sphere of hydrogen. Because a star is so massive, the gravitation pull on the hydrogen atoms is sufficient to overcome the repulsion between the two nuclei to force them together to form an unstable $^{2}_{2}He$ nucleus. This immediately ejects a positron, leaving deuterium, $^{2}_{1}H$, and releasing a significant amount of energy. In the cascade of reactions deuterium fuses with another hydrogen to give $^{3}_{2}He$, and two of these combine to form helium, ejecting two high-energy protons in the process.

In stars that are larger and heavier than our sun, the "triple alpha process" is the dominant nuclear reaction. In this, helium nuclei fuse to eventually form carbon, releasing significant energy in the process.

One of the great challenges in physics and engineering today is to replicate fusion of this sort under controlled conditions, harvesting the energy released and converting it, indirectly, into electrical power. The extremely high temperatures and pressures that are required to initiate and sustain fusion reactions thwarted, thus far, attempts to build a fusion reactor that is "break even" in terms of the energy released relative to the energy required to produce the fusion events. Uncontrolled fusion is certainly possible, and fusion bombs exist, but these typically use an advanced fission bomb to create the temperatures and pressures necessary to promote the fusion of the lighter elements. Clearly, this approach does not work in the laboratory! Work on fusion reactors continues at a fast pace and includes novel approaches such as *aneutronic* fusion reactions that utilize proton-boron fusion to produce charged particles rather than a barrage of neutrons. The advantage here is that few neutrons are produced, reducing the need for shielding, and the charged particles formed can potentially be captured *directly* as electricity.