Lesson 47: Antimatter

The name **antimatter** might have you start thinking about stuff from sci-fi movies, but it is actually a real thing!

Illustration 1: Paul Dirac

- In 1928 the British Physicist **Paul Dirac** was playing around with some of the more modern physics ideas of the time.
  - Using the work of Wolfgang Pauli, Einstein's Theory of Relativity, and Schrodinger's Wave Equation, Dirac came up with a formula that made an odd sounding prediction. If electrons exist (and we know they do) there should also exist a positive particle with the same mass!
- In 1932 **Carl Anderson** took a photo of a cloud chamber that showed the existence of this strange particle.
  - Anderson verified this because the radius of the particle's path allowed him to calculate its charge-to-mass ratio (which was the same as an electron's), and he could see that the path in the magnetic field could only happen if the particle was positive.
- This was the first antimatter particle discovered. It is usually called a positron, although you can also call it an antielectron.

This means we have to change the way we think of the structure of matter.

- Up to now, we only used three fundamental particles to describe the building blocks of all matter; electrons, protons, and neutrons.
- We now have to expand our way of thinking to include the existence of antimatter.
  - When writing down symbols for charged antimatter, you usually keep the same symbol and just change the sign. If the antimatter is neutral, put a bar above the symbol.

Particle	Symbol	Antiparticle	Symbol
Electron	e^-	Positron	e^+
Proton	p^+	Antiproton	p^-
Neutron	n	Antineutron	$\bar{n}$

Antimatter has some interesting qualities.

- When matter and antimatter collide, a process called **particle-antiparticle annihilation** happens.
  - In this process, the two particles cause the total destruction of each other, transforming all of their mass into energy according to mass-energy equivalence ($E=mc^2$).

Did you know?

Particle-antiparticle annihilation might sound like something from sci-fi movies, but it is very possible that it may one day be a source of energy. The idea in movies of containing antimatter in a magnetic field, and then combining it with matter is physically possible.

Example 1: Particle-antiparticle annihilation does happen in stars. One such reaction involves an electron and a positron colliding...

$$e^+ + e^- \rightarrow 2\gamma$$

Assuming the gamma photons are identical, determine the energy of one of these photons released.

This annihilation will cause the complete transformation of the electron and positron into energy according to mass-energy equivalence. Keep in mind that the only thing that makes them different is that they have different charges. They both have the exact same mass, the mass of an electron. Let's calculate the equivalent energy of one electron...

$$E = mc^2 = 9.11e\text{-}31\ (3.00e8)^2 = 8.199e\text{-}14 = 8.20e\text{-}14\ J$$

Since there are two of these particles, the **total** energy released is double this, 1.64e-13 J. But, remember the question only asked for the energy of one gamma photon, and there were two of those, so we'd have to divide by two anyways. *Each* particle is annihilated to produce its own gamma photon that *each* has an energy of **8.20e-14 J**.

Particle-antiparticle annihilation has even led to some interesting technology, like **PET** scanners in hospitals.

- **PET** stands for **P**ositron **E**mission **T**omography.
  - A radioactive isotope, such as fluorine-18, is injected into a person.
  - As it moves throughout the persons body, it emits positrons through beta positive decays.
    - I know this sounds dangerous, since it sounds like the persons body should explode in a burst of gamma radiation.
    - Nothing that dramatic happens. As you saw in the example above, the amount of energy of those gamma rays are actually quite small. As the positrons hit electrons in the person's body, small gamma rays are emitted out of the person.
  - While these gamma rays are coming out, gamma ray detectors spin around the person.
    - Depending on where they detect gamma rays coming from, they can draw out a 3D map of the inside of a person.
- Due to changes in technology, most PET scanners in hospitals are being replaced with PET/CT scanners, devices that combine the advantages of PET scanners with CT (computed tomography) scanners.

Illustration 2: PET Scanner.

Homework

p839 #6-8