Antimatter
Revised 4-28-04

Two remarkable achievements in physics in the early 20th century were the development of the theory of relativity by Einstein and the quantum theory by a number of people, including Einstein. Around 1930, the British theoretical physicist Paul Dirac, in trying to unify these two theories, wrote down an equation describing an electron – now known as the Dirac equation – that implied a very remarkable thing: that besides the electron there should be another particle with the same mass as the electron and the same amount of electric charge, but with the opposite sign of the charge, and that these two particles coming together would annihilate each other with the liberation of their entire mass into energy in the form of photons, in accordance with Einstein's famous equation E = mc2. This particle was discovered experimentally a few years later and called the positron, or anti-electron.

It was clear from Dirac's theory that all the rest of the particles in the world should also have corresponding antiparticles. For instance, for the proton there should be an antiproton with the same mass as the proton but opposite charge, and a proton and an antiproton coming together would annihilate each other with a great explosion of energy being liberated in the form of lighter particles called pi-mesons and radiation.

Similarly, there should be anti-neutrons (which have no charge but other properties – e.g., spin and magnetic moment – opposite to those of the neutron) that would annihilate ordinary neutrons.

If we have anti-electrons, antiprotons, and antineutrons, we should be able to make anti-atoms; for example an anti-hydrogen atom consisting of a negatively-charged antiproton at the center with a positively charged anti-electron (positron) orbiting around it. The masses of the hydrogen and anti-hydrogen atoms would be the same. A clock made out of antimatter would run the same as a clock made out of matter – but the two would annihilate each other if brought together.

A baffling question: if anti-matter can exist, where is it? It appears that the universe, at least in our vicinity, is composed entirely of ordinary matter. We don't expect matter and antimatter to co-exist in the earth or a star, because they would annihilate each other, but are there islands of antimatter in the universe? It's difficult to know for sure, because the light and its spectrum emitted by an anti-star would be the same as that from a star.

According to present cosmological ideas, when the big bang started the universe it was composed entirely of radiation. It then cooled down, creating pairs of particles and antiparticles in equal numbers, but there was a slight breaking of symmetry that led to the eventual preponderance of one over the other, which is believed to be the present state of affairs.

If pockets of anti-matter could be found and combined with ordinary matter in some way, large amounts of energy would be released.

Energy released in uranium fission = 177 MeV*
Energy released in DT fusion = 17.6 MeV
Energy released in electron-positron annihilation = $2m_ec^2$ = 1.02 MeV
Energy released in proton-proton annihilation = $2m_pc^2$ = 1862 MeV

*MeV = million electron volts = convenient sized unit for measuring nuclear energies:
1 Mev = 1.60×10^{-13} Joule

According to Sara's paper on *The Literature of Anticipation*, to reach one half the speed of light a spaceship would have to carry an amount of fuel equal in weight to about 80 times the weight of the spaceship payload; e.g., 800 tons of fuel for a 10 ton payload.

Pound for pound, proton-antiproton annihilation produces about one billion (10^9) times as much energy as the chemical reaction $2H_2 + O_2 \rightarrow 2H_2O$. This would reduce the weight of fuel that had to be carried from 800 tons of hydrogen and oxygen to **1 gram** of protons and antiprotons.