2.3.1 Particles and antiparticles

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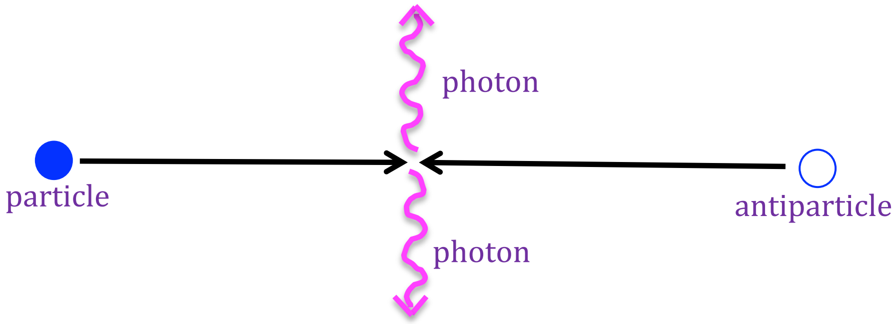
The existence of antiparticles was proposed by the theoretical physicist Paul Dirac in 1928. He proposed that:

1) *for every particle, there exists a corresponding antiparticle.*
2) *If the particle has a charge, then the antiparticle has the opposite charge.*
3) *The antiparticle has the same rest mass as the particle.*

Annihilation

When an antiparticle meets its corresponding particle the two should annihilate, releasing energy as two photons.



The combined energy of these two photons should be equal to the total energy (kinetic energy + rest energy) of the particle and antiparticle. *(Note: the rest energy of a particle is the energy 'locked up' in its mass m_o and can be calculated using the relationship $E=m_oc^2$, where c is the speed of light = $3 \times 10^8 ms^{-1}$).*

(1)✐Using the relationship above, calculate the rest energy of an electron with a rest mass of 9.109×10^{-31}kg.

You should find this is a very small number when written in joules. This is often the case in calculations involving very small particles! For this reason, scientists often use another unit, called the electron-volt (*eV*) for small amounts of energy. *($1eV = 1.6 \times 10^{-19}J$)*

Often the electron-volt is used with the prefix *k* (for kilo), *M* (for mega) or *G* (for giga). For example:
1000eV = 1keV
1000000eV = 1MeV
1000000000eV = 1GeV

(2)✐Write 150000eV in keV, in MeV and in GeV.

(3)✐How many joules is 150000eV?

If you look at the diagram for annihilation, 2 photons are produced, which travel in opposite directions (to conserve momentum). Both photons have the same energy. Therefore, their frequencies are the same.

Remember that the energy of a photon E = hf, where h is the Planck Constant (=6.63 x $10^{-34}m^2kgs^{-1}$), and f is the frequency.

The energy of the annihilation is shared between the two photons. Therefore:

the energy of one photon = ½ x energy of annihilation

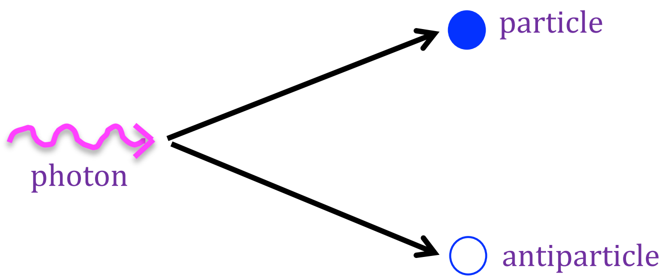
If the particles collide with negligible kinetic energy (i.e. not moving very fast), the energy of annihilation is just the rest energy of the two particles. In this case:

$$energy\ of\ one\ photon = rest\ energy\ of\ one\ particle$$
$$hf = m_o c^2$$

(4)✐This is actually the <u>minimum energy</u> that a photon produced during annihilation will have. Why?

Pair production

We have seen that a particle and antiparticle can produce electromagnetic radiation (annihilation). The opposite can also occur where a photon can produce a particle and antiparticle. This is called pair production.



In this situation, the photon energy is converted into the rest energy of the two particles (essentially, giving them mass) and any extra energy goes into the kinetic energy of the two particles. The minimum energy required (i.e. just to create the mass of the particle and antiparticle) is given by:

$$photon\ energy = 2\ x\ rest\ energy\ of\ the\ particle$$
$$hf = 2m_o c^2$$

(5)✐What is the minimum energy of the photon required to produce a proton-antiproton pair? (rest mass of proton = 1.67 x 10^{-27}kg)

(6)✐What is the minimum frequency of the photon required to produce a proton-antiproton pair?