Particles and antiparticles

Antimatter

- Each particle type has a corresponding **antiparticle** with the same mass and rest energy but with **opposite charge** (if charged).
- All particles are known as **matter** and antiparticles are known as **antimatter**.

(rest energy = energy when particle is not moving)

(Mass increases as kinetic energy increases ($E = mc^2$))

Particle / Antiparticle	Symbol	Relative Charge	Mass (kg) (Resting)	Rest Energy (MeV)
proton	p	+1	1.673×10^{-27}	938(.3)
antiproton	$\bar{p}$	-1		
neutron	n	0	1.675×10^{-27}	939(.6)
antineutron	$\bar{n}$			
electron	e^-	-1	9.11×10^{-31}	0.511
positron	e^+	+1		
neutrino	ν_e	0	0	0
antineutrino	$\bar{\nu}_e$			

(These two are equivalent (only units are changed) → Due to $E = mc^2$)

How is antimatter discovered?

- Antimatter was predicted in 1928 by English physicist **Paul Dirac**.
- **Einstein** had shown that the mass of a particle increases the faster it travels due to $E = mc^2$ (energy and mass is equivalent)
- Einstein said that the mass of a stationary particle (rest mass) (m_0) corresponds to rest energy (m_0c^2) locked up as mass.
- Dirac predicted the existence of antiparticles that would unlock rest energy during annihilation (a particle or corresponding antiparticle meet).

Dirac's theory of antiparticles

- For every type of particle, there is a corresponding antiparticle that:
  - ↳ annihilates the particle and itself if they meet, converting their total mass into photons.
  - ↳ has same rest mass as the particle.
  - ↳ has opposite charge to the particle.
- **Pair production:** A photon with sufficient energy passing near a nucleus or an electron can change into a particle-antiparticle pair.

What are electron volts (MeV)?

$1\ \text{MeV} = 1.60 \times 10^{-13}\ \text{J}$

- One electron volt is defined as the energy transferred when an electron is moved through a potential difference of 1 volt.
- Given the rest mass of a particle/antiparticle, its rest energy in MeV can be calculated using $E = mc^2$
- Voltage = Energy / Charge $(E/e) \Rightarrow E = eV$

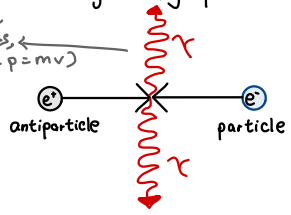
Annihilation

- Annihilation occurs when a particle and a corresponding antiparticle meet and their mass is converted into EM energy in the form of photons. (mass and energy are equivalent due to $E = mc^2$).
- All the mass of the particle and antiparticle gets converted to energy in the form of gamma ray photons.

How are energy stored in "mass"?

- Rest energy (energy "stored in mass") = $E = mc^2$ (this equation only applies to resting mass.
- The notation for rest energy is E_0.

(Even though light is massless, it has momentum ($p = mv$))



Conservation of energy in annihilation

- Energy cannot be created nor destroyed.
- The energy of the two photons, $2hf_{min}$ (derived from equation $E = hf$) should equal to the rest energy of the particle and antiparticle:

$$2hf_{min} = 2E_o$$

↓ factoring

Minimum energy of each photon produced, $hf_{min} = E_o$ ← rest energy (mc^2)

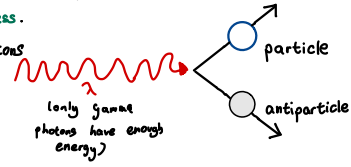
$$^{0}_{-1}\beta^{-} + ^{0}_{+1}\beta^{+} \Rightarrow 2\,^{0}_{0}\gamma$$

Use of annihilation

- PET Scans (Positron emitting tomography) work by putting a positron-emitting isotope into the blood, and detecting the gamma rays produced by the electron-positron annihilation that occurs.
- The gamma rays are always produced in pairs moving in opposite directions, so they're easily distinguished by a scintillator. (machine to form an image)

Pair Production

- In pair production, a photon creates a particle and a corresponding antiparticle and vanishes in the process.
- Pair production only happens if there is enough energy to produce the masses of the particles.
- It must always produce a particle and its corresponding antiparticle because certain quantities must be conserved: energy, momentum, baryon number, lepton number, charge, strangeness.
- Pair production can also be used to produce protons by firing two protons with a lot of kinetic energy. Energy is converted to more particles.



Conservation of energy in pair production

- Energy cannot be created nor destroyed.
- One photon must produce a particle - antiparticle pair - the minimum energy being the total rest energy of the particles that are produced.

→ Rest energy of a particle is the amount of energy that would be produced if all of its mass was transformed into energy.

Minimum energy of photon needed = $hf_{min} = 2E_o$ ← rest energy of particle type produced in MeV (mc^2)