

Particles, antiparticles and their interactions

2

Constituents of an atom

Simple model of an atom:

An atom is made up of:

- a nucleus, where most of its mass is concentrated, that is comprised of protons and neutrons
- electrons that sit in shells outside the nucleus

Specific charge: the ratio of charge of an ion or particle to its mass

Isotope: two or more of the same element with the same number of protons but a different number of neutrons in their nuclei

Stable and unstable nuclei

Strong nuclear force: the attractive force between nucleons, which binds them together in the nucleus

Unstable nucleus: a nucleus that has an imbalance of neutrons and protons, creating insufficient binding energy from strong nuclear forces to hold the nucleus together

You will be expected to know that unstable nuclei undergo radioactive decay, emitting radiation to achieve stable states.

Properties of the strong nuclear force

The strong nuclear force compensates for the repulsive electrostatic force between protons in the nucleus.

- It has a range of 3–4 fm.
- It has the same effect between two protons as it does between a proton and neutrons or between two neutrons.
- It is an attractive force from 3–4 fm to 0.5 fm.
- It is a repulsive force at separation less than 0.5 fm.
- It is a repulsive force at this separation to ensure that neutrons and protons are not squashed into one another.

Charge and mass of constituent parts

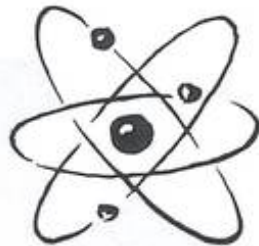
	Charge	Mass
Electron	-1.6×10^{-19} C	9.11×10^{-31} kg
Proton	$+1.6 \times 10^{-19}$ C	$1.67(3) \times 10^{-27}$ kg
Neutron	0 C	$1.67(5) \times 10^{-27}$ kg

Nuclide notation

Nuclei can be written in the following form:



where A is the mass number (number of nucleons) and Z is the proton number (number of protons).

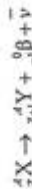


Types of decay

Alpha decay:

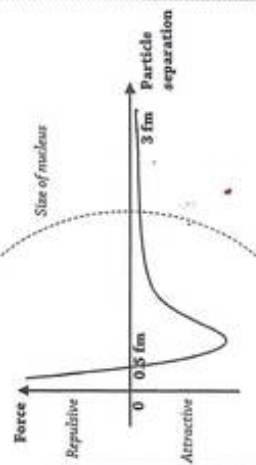


Beta decay:



Note: The existence of the neutrino was first hypothesised in order to account for the conservation of energy in the beta decay.

The conservation of energy law states that energy cannot be created or destroyed. This applies to all decays.



Particles and antiparticles

Photon energy:

$$E = hf$$

For every particle there is an antiparticle. A particle's antiparticle has an equal but opposite charge, and the same rest mass and energy as its particle counterpart.

$$E = \frac{hc}{\lambda}$$

$$f = \frac{c}{\lambda}$$

Properties of antiparticles

Particle	Charge, q	Rest mass, m_0	Rest energy, E_0
Positron	$+1.6 \times 10^{-19}$ C	9.11×10^{-31} kg	0.511 MeV
Antineutron	0 C	$1.67(5) \times 10^{-27}$ kg	939.6 MeV
Antiproton	-1.6×10^{-19} C	$1.67(3) \times 10^{-27}$ kg	938 MeV
Antineutrino	0 C	0 kg	0 eV

Pair production

- Pair production** occurs when a photon creates a particle and its corresponding antiparticle, disappearing in the process.
- $hf_{min} = 2E_0$
- A photon with energy, $E < 2E_0$, could, therefore, not create a particle-antiparticle pair.

Annihilation

- Annihilation** occurs when a particle and its corresponding antiparticle meet.
- Their individual masses are converted into the radiation energy of two photons.
- $2E_0 = 2hf_{min}$

Four fundamental interactions/forces:

Strong nuclear:

- Force between nucleons
- Exchange particle – gluon

Weak nuclear:

- Force causes changes in nucleus
- Exchange particle – W boson / Z boson

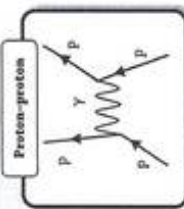
Electromagnetic:

- Force between charged particles
- Exchange particle – virtual photon

Gravity:

- Force between masses
- Exchange particle – hypothesised graviton

Particle interactions



Exchange particles explain the forces acting between elementary particles.

Electromagnetic J

