1 Matter and radiation

1.1 Inside the Atom

Atoms can only be imaged with electron microscopes. Although we cannot see inside atoms we know from **Rutherford's alpha-scattering investigations** that every atom contains

- A positively charged **nucleus** composed of protons and neutrons.
- **Electrons** surrounding the nucleus.

A **nucleon** is a proton or a neutron in the nucleus.

Electrons are negatively charged, they are held in the atom by the electrostatic force of attraction between them and the nucleus.

- The nucleus contains most of the mass of the atom.
- Its diameter is of the order of 0.00001 times the diameter of the atom.

	Charge/C	Relative charge	Mass/kg	Relative mass
proton	$+1.6 \times 10^{-19}$	1	1.6×10^{-27}	1
neutron	0	1	1.6×10^{-27}	1
electron	-1.6×10^{-19}	1	9.1×10^{-31}	0.0005

where relative charges and masses are relative to that of the proton.

Notice that

- The electron has a much smaller mass than the proton or neutrons.
- The proton and neutron have almost equal mass.
- The electron has equal and opposite charge to the proton, the neutron is uncharged.

An **uncharged atom** has equal number of protons and electrons. An uncharged atom gains or loses electrons to become an **ion**.

Isotopes

Every atom of a given element has the same number of protons.

- The **proton number** of an element is also called the **atomic number** Z.
- The **nucleon number** of the atom A is the total number of protons and neutrons in an atom.

The nucleon number A is sometimes called the **mass number** because it is approximately the mass of the atom in relative units, as the mass of a proton or neutron is approximately 1.

Isotopes are atoms with the same number of protons and different number of neutrons.

Each type of nucleus is called a **nuclide**, and is labelled using the **isotope notation**.

$$^{A}_{Z}X$$

where X is the chemical symbol of the element. The number of neutrons is given by $A - Z$.

Specific Charge

The **specific charge** of a charge particle is defined as its charge divided by mass

$$\text{specific charge} = \frac{\text{charge}}{\text{mass}}$$

The electron has the largest specific charge of any particle.

1.2 Stable and Unstable Nuclei

We know the **strong nuclear force** exist because the nuclei of a stable isotope do not disintegrate - there must be a force holding them together. The strong nuclear force

- Overcomes the **electrostatic force of repulsion** between the protons in the nucleus.
- Keeps the protons and neutrons together.

The strong nuclear force has the same effect between any two **nucleons**.

It has a range <u>no more than 3fm</u> - about the same as the diameter of a small nucleus. In contrast of the electrostatic force's infinite range. It is an **attractive force** from 3fm to 0.5fm, and a **repulsive force** smaller than that to prevent neutrons and protons being pushed into each other.

$1\text{fm} = 10^{-15}\text{m}$

The equilibrium separation is where the **force curve** (picture it in your head) crosses the x-axis.

<u>Naturally occurring</u> radioactive isotopes release three types of radiation.

Alpha radiation α

consists of **alpha particles** ${}^4_2\alpha$ each comprise of two protons and two neutrons.

$${}^A_Z X \rightarrow {}^{A-4}_{Z-2}Y + {}^4_2\alpha$$

The product nucleus with $Z - 2$ protons belongs to a different element Y.

Beta radiation β

consists of fast-moving electrons know as **beta particles** ${}^{0}_{-1}\beta$.

A neutron in the nucleus changes to a proton, a beta particle is created when the change happens and is emitted instantly, an **antineutrino** $\bar{\nu}$ is also emitted. The atomic number **increases by 1** to $Z + 1$.

$${}^A_Z X \rightarrow {}_{Z+1}^{\ \ A}Y + {}^{\ 0}_{-1}\beta + \bar{\nu}$$

This type of change happens to nuclei with too many neutrons.

Gamma radiation γ

is an electromagnetic radiation emitted by an unstable nucleus.

- Passes through thick metal plates.
- Has no mass and no charge.

It is emitted by a nucleus with too much energy, following an alpha or beta emission.

Discovery of the neutrino

The energy spectrum of beta particles showed that beta particles were released with kinetic energies up to a maximum depending on the isotope, where each unstable nucleus lost a certain amount of energy in the process.

Then either

- Energy was not conserved in the change, or
- Some of it was carried away by mystery particles - called **neutrinos** and **antineutrino**.

The hypothesis was proven after 20 years, where antineutrinos were detected from their interaction with the **cadmium nuclei** in a tank of water, installed next to a nuclear reactor as a controllable source of neutrinos.

We now know billions of neutrinos from the sun pass through our bodies without interacting.

1.3 Photons

Visible light is just a small part of the spectrum of **electromagnetic waves**. Our eyes cannot detect the other parts.

In a vacuum, all electromagnetic waves travel at the speed of light $c = 3.00 \times 10^8 \text{ms}^{-1}$. Where the frequency f and wavelength λ of electromagnetic radiation is related by

$$f\lambda = c$$

where the wavelength of light λ is often expressed in nanometres ($1\text{nm} = 1 \times 10^{-9}\text{m}$). Visible light have wavelength between 400nm and 700nm.

An electromagnetic wave consists of an **electric wave** and **magnetic wave** which travel together and vibrate

- At **right angles to each other** and to the direction which they are travelling.
- **In phase with each other** - the two waves reach a peak together.

The Photon Theory of Light

Electromagnetic waves are emitted by a charged particle when it loses energy, this happens when

- A fast-moving electron is **stopped**, slowed down or changed direction.
- An **atomic electron** moves to a different shell of lower energy.

Electromagnetic waves are emitted in short bursts of waves, each burst is a packet of waves referred to as a **photon**. The **photon theory** was established to explain the **photoelectric effect** - the emission of electrons from a metal surface when light is directed at the surface.

The energy E of a photon depends on its frequency f

$$E = hf$$

where $h = 6.63 \times 10^{-34}$Js is **Planck's constant**.

Power of Laser Beam

A **laser beam** consists of photons of the same frequency. The power of a laser beam is the energy per second transferred by the photons.

$$P = nhf$$

where n is the number of photons in the beam passing a fixed point each second.