# 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 | $1.6 \times 10^{-27}$ | 1 |
| neutron | 0 | 1 | $1.6 \times 10^{-27}$ | 1 |
| electron | $-1.6 \times 10^{-19}$ | 1 | $9.1 \times 10^{-31}$ | 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 no more than 3fm - 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.

Naturally occurring radioactive isotopes release three types of radiation.

#### Alpha radiation $\alpha$

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

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

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

#### Beta radiation $\beta$

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 $Z+1$.

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

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

### Gamma radiation $\gamma$

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.