2.1 The nuclear atom

Nature of science:

Evidence and improvements in instrumentation—alpha particles were used in the development of the nuclear model of the atom that was first proposed by Rutherford. (1.8)

Paradigm shifts—the subatomic particle theory of matter represents a paradigm shift in science that occurred in the late 1800s. (2.3)

Understandings:

- Atoms contain a positively charged dense nucleus composed of protons and neutrons (nucleons).
- Negatively charged electrons occupy the space outside the nucleus.
- The mass spectrometer is used to determine the relative atomic mass of an element from its isotopic composition.

Applications and skills:

- Use of the nuclear symbol notation ${}^{A}_{Z}X$ to deduce the number of protons, neutrons and electrons in atoms and ions.
- Calculations involving non-integer relative atomic masses and abundance of isotopes from given data, including mass spectra.

Guidance:

- Relative masses and charges of the subatomic particles should be known, actual values are given in section 4 of the data booklet. The mass of the electron can be considered negligible.
- Specific examples of isotopes need not be learned.
- The operation of the mass spectrometer is not required.

International-mindedness:

- Isotope enrichment uses physical properties to separate isotopes of uranium, and is employed in many countries as part of nuclear energy and weaponry programmes.

Theory of knowledge:

- Richard Feynman: "If all of scientific knowledge were to be destroyed and only one sentence passed on to the next generation, I believe it is that all things are made of atoms." Are the models and theories which scientists create accurate descriptions of the natural world, or are they primarily useful interpretations for prediction, explanation and control of the natural world?
- No subatomic particles can be (or will be) directly observed. Which ways of knowing do we use to interpret indirect evidence, gained through the use of technology?

Utilization:

- Radioisotopes are used in nuclear medicine for diagnostics, treatment and research, as tracers in biochemical and pharmaceutical research, and as "chemical clocks" in geological and archaeological dating.
- PET (positron emission tomography) scanners give three-dimensional images of tracer concentration in the body, and can be used to detect cancers.

Syllabus and cross-curricular links:
Topics 11.3, 21.1 and options D.8 and D.9—NMR
Options C.3 and C.7—nuclear fission
Option D.8—nuclear medicine

Aims:

- **Aim 7**: Simulations of Rutherford's gold foil experiment can be undertaken.
- **Aim 8**: Radionuclides carry dangers to health due to their ionizing effects on cells.

UNIT 2.1 – THE NUCLEAR ATOM

ATOM MASS & CHARGE

Subatomic Particle	Symbol	Mass (kg)	Relative Mass	Charge (c)	Relative Charge
Proton	p	1.6725 * 10^-27	1	+1.6022 * 10^-19	1
Neutron	n	1.6749 * 10^-27	1	0	0
Electron	e-	9.1094 * 10^-31	5 * 10^-4	-1.6022 * 10^-19	-1

IONS AND ISOTOPES

IONS

Elements have the ability to gain or lose electrons to form charged particles known as ions.

Cations: Positive
Anions: Negative

$^{23}{}_{11}Na \rightarrow {}^{23}{}_{11}Na^{+}$

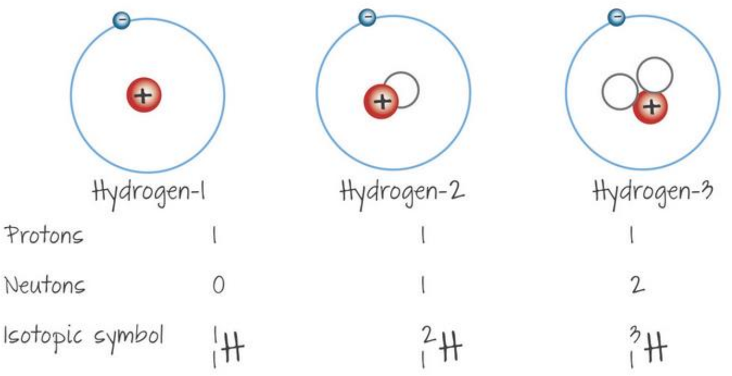
a sodium atom   a sodium ion

$11p^{+}$ / $12n$ / $11e^{-}$ $11p^{+}$ / $12n$ / $10e^{-}$

ISOTOPES

Elements can exist naturally in multiple forms.

Number of protons stays the same, number of neutrons differs.



Note: Isotopes have different mass numbers

MASS SPECTROMETER

A mass spectrometer is an instrument that's used to separate sample based on their mass, which can then be used to figure out the mass of certain atoms.

COMPONENTS

- **Vaporisation**: Sample is vaporised (can start as a liquid or solid)
- **Ionization**: Electrons are used to ionize the atoms, making them positive. The electrons are knocked off (taken away)
- **Acceleration**: A strong electric field accelerates the ions
- **Deflection**: Magnetic fields deflect the ions according to their mass, the heavier ions will be deflected less.
- **Detection**: Electronic detection occurs of the ion beams and their intensities are measured.
- **Mass spectrum**: The data is recorded as a mass spectrum (still on a carbon 12 scale). It graph the **RIM** against the **% abundance**.

RELATIVE ISOTOPIC MASS (R.I.M)

The relative mass of each of the isotopes in an element. All isotopic masses are measured relative to **carbon 12** (which has a mass of 12 units).

^{12}C = mass of 12 units

^{1}H = 1.008 = 1/12 of the mass of carbon 12

RELATIVE ATOMIC MASS (R.A.M)

The weighted average of its mutually occurring isotopes, taking into account their abundance levels.

MASS TO CHARGE RATIO

Mass:charge = m/z

When atoms are **ionized** they are bombarded with spare electrons, causing one electrons on the atom to fly off, making the atom a positively charged ion (1+) in most cases. Sometime 2 electrons are knocked off, causing a 2+ charge, making it be deflected twice as much since it has **double the charge** (but not half the mass).

The smaller the mass:charge ratio, the more the atom will be deflected.

This explains the small speaks that appear on the mass spectrum.

$$^{24}Mg^{2+}$$

This ion has a mass:charge ratio of 24:2 = 12. The **mass spectrum** will now show a peak at 12.

MASS SPECTRUM

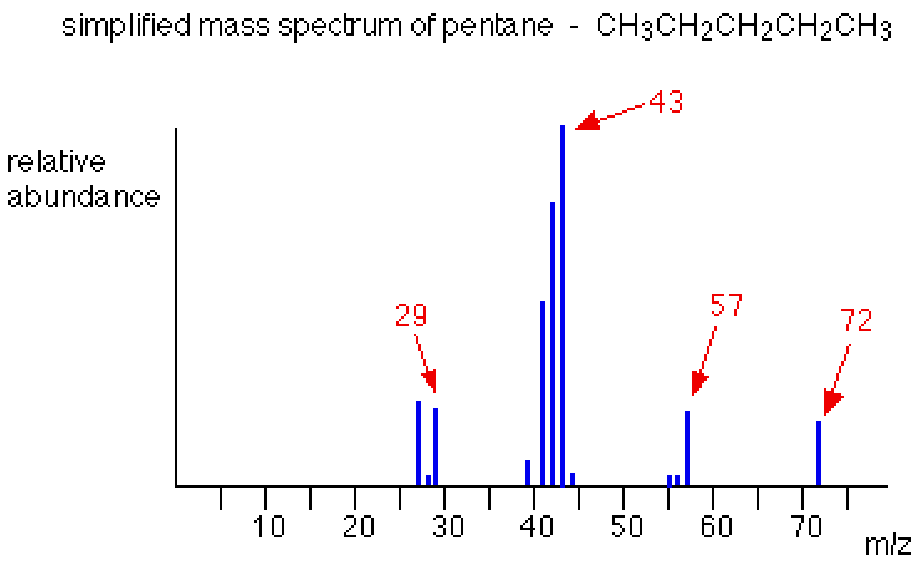
CALCULATING R.A.M

Calculating RAM →

$$\mathbf{R.A.M} = \sum \frac{(\mathrm{RIM} * \%)}{100}$$

More common equation →

$$\mathbf{Ar} = \sum \frac{(\mathrm{Ir} * \%)}{100}$$



NUCLEAR SYMBOL NOTATION

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

A = Mass number = number of protons + number of neutrons
Z = Atomic number = Number of protons
X = Atomic symbol

A sample of element X contains 69% of ^{63}X and 31% of ^{65}X. What is the relative atomic mass of X in this sample?

A. 63.0

B. 63.6

C. 65.0

D. 69.0

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$$A_r = \frac{\Sigma\, I_r \times \%}{100}$$

$$= \frac{63 \times 69}{100} + \frac{65 \times 31}{100}$$

$$= 63.62$$