

Week 1 - Nuclear chemistry

Significant figures

Rules:

- Non-zero digits always count (e.g., 424 → 3 s.f.)
- Zeros between non-zero digits count (e.g., 40024 → 5 s.f.)
- Leading zeros (e.g., 0.024) do not count (→ 2 s.f.)
- Trailing zeros after a decimal count (e.g., 42.400 → 5 s.f.)
- Maintain precision in calculations (e.g., 13.468 ± 0.001 has 5 s.f.)

Units

- There are 7 fundamental units: kilogram (kg), meter (m), candela (cd), second (s), ampere (A), kelvin (K) and mole (mol)
- Newton (N) → $Force (N) = Mass (kg) \times Acceleration (m s^{-2})$
- Joules (J) → $Energy (J) = Force (kg m s^{-2}) \times distance (m)$

Isotopes

- Atoms of the same element but different mass numbers

Nucleogenesis (how elements are made) → this happens inside stars via nuclear fusion, where lighter atoms combine to form heavier ones

The fusion process (hydrogen → helium) - the proton-proton chain

1. 2 hydrogen nuclei fuse → forms deuterium (hydrogen isotope with 1P 2N), a positron is released
2. Deuterium fuses with another hydrogen → forms helium-3 and a gamma ray
3. 2 helium-3 atoms fuse → forms helium-4 (a stable nucleus) and ejects 2P

During fusion, some mass is lost → missing mass is converted to energy → this is the source of the sun's heat and light, and powers all stars

Formation of heavier elements:

As stars run out of hydrogen, they start fusing helium into heavier elements → fusing up to iron is the limit as fusion beyond iron **consumes** energy (endothermic) rather than releasing energy (exothermic)

Supernova

When a massive star can't fuse iron, **its core collapses and triggers a supernova** (an enormous explosion) → in the explosion, the extremely high energy and pressure allow the formation of elements heavier than iron - these elements are then scattered into space, becoming part of new stars, planets etc.

Radioactivity

2 types of atomic nuclei: stable and radioactive

- Radioactive nuclei decay spontaneously to become more stable

Half life

- Amount of time for half of radioactive atoms in a sample to decay

Exponential decay equation: $N = N_0 e^{-kt}$

N = no. of atoms left

N₀ = original no. of atoms

k = Decay constant → tells you how quickly substance decays

Half life equation → $t_{1/2} = \ln(2)/k$

Activity (A)

- A = rate of decay - how many atoms decay per sec → Measured in becquerels (Bq)
- $A = kN$, where N = no. of radioactive atoms
- Specific activity = activity per gram of substance
- Molar activity = activity per mole of substance

Radiocarbon dating (c-14) dating

- Used to calculate how long ago something died

$$t = 8033 \times \ln\left(\frac{A_0}{A_t}\right)$$

A₀: activity of a modern (fresh) sample

A_t: activity of the ancient sample

Week 2: Nuclear chemistry & wave theory

Nuclear stability & predicting radioactive decay

Causes of nuclei instability

- Too many protons → repulsion too strong
- Too many neutrons → weak internal binding

N:Z ratio → Stable isotopes lie within the “zone of stability”

Decay = Move Toward Stability

Types of radioactive decay

| Decay Type | What Happens | Used When | Example |
|-----------------------------------|--|----------------------------------|---|
| Alpha (α) | Lose 2 protons + 2 neutrons (He nucleus) | Nucleus too big | ${}_{92}^{238}\text{U} \rightarrow {}_{90}^{234}\text{Th} + {}_2^4\text{He}$ |
| Beta-minus (β⁻) | Neutron → proton + electron | Too many neutrons (N:Z too high) | ${}_{6}^{14}\text{C} \longrightarrow {}_{7}^{14}\text{N} + {}_{-1}^0\text{e}$ |
| Beta-plus (β⁺) | Proton → neutron + positron | Too many protons (N:Z too low) | ${}_{9}^{17}\text{F} \rightarrow {}_{8}^{17}\text{O} + {}_{+1}^0\text{e} + \nu_e$ |
| Electron capture | Electron + proton → neutron | Same as β ⁺ decay | ${}_{33}^{73}\text{As} + {}_{-1}^0\text{e} \rightarrow {}_{32}^{73}\text{Ge}$ |
| Neutron emission | Lose 1 neutron | Mass reduction | ${}_{2}^7\text{He} \rightarrow {}_{2}^6\text{He} + {}_0^1\text{n}$ |