LESSON 4.3.1

Atomic Nuclei, Isotopes and Mass-Energy Ideas

A tiny nucleus contains protons and neutrons and almost all of an atom's mass. Electrons occupy the surrounding region. Nuclear symbols tell us what is inside.

READ THE NUCLEAR SYMBOL

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

A = nucleon (mass) number

Total protons + neutrons; a count, not kg.

Z = proton (atomic) number

Identifies the element; nuclear charge = +Ze.

Neutron number = A - Z

ISOTOPES: SAME Z, DIFFERENT A

Isotopes have the same proton number but different neutron numbers. Their neutral atoms have the same electron arrangement, so their chemical properties are very similar.

CARBON-12

$$ {}^{12}_{6}C $$

6 protons

6 neutrons

6 electrons if neutral

Same element; different neutron count.

CARBON-14

$$ {}^{14}_{6}C $$

6 protons

8 neutrons

6 electrons if neutral

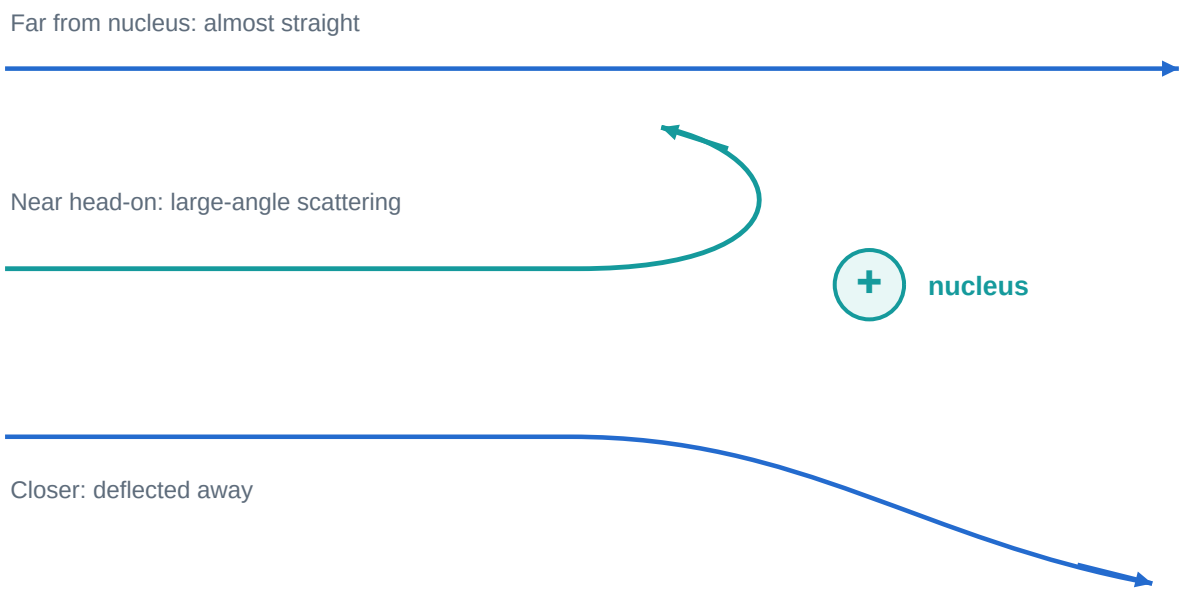
Same element; different neutron count.

Ion formation changes the electron count, not A or Z. A carbon ion with charge +2e still has 6 protons, but only 4 electrons. Proton charge is +e; neutron charge is zero.

1 Scattering revealed a compact nucleus

Alpha particles are helium nuclei: 2 protons and 2 neutrons. A narrow beam struck thin metal foil; a fluorescent screen detected the scattered particles.

REPULSION BY A SMALL POSITIVE NUCLEUS



Representative paths near one nucleus; sizes and angles are schematic.

1. MOST ALPHA PARTICLES PASS THROUGH

Most trajectories miss the tiny nuclear region and experience little deflection. The atom is mostly empty space, rather than a uniformly dense ball.

2. SOME ARE DEFLECTED; VERY FEW TURN BACK

A concentrated positive charge can strongly repel an approaching positive alpha particle. The rarity of large deflections shows that this region is small.

3. MASS AND POSITIVE CHARGE ARE CONCENTRATED

The massive nucleus can turn an alpha particle through a large angle. A diffuse positive-charge model could not explain the observed backscattering.

This evidence did not itself establish neutrons or fixed electron orbits.

2 Mass is associated with rest energy

Mass number A counts nucleons. Actual rest mass m is a measured quantity and is not an integer count.

$$E_0 = mc^2 \qquad \Delta E_0 = \Delta m\, c^2$$

A decrease in the total rest mass of reaction products can appear as kinetic energy or radiation. Total energy is conserved; rest mass alone need not be conserved in a reaction.

For a rest-mass decrease, energy released = (initial mass - final mass)c^2.

KEEP ENERGY UNITS AND MASS UNITS SEPARATE

$$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$$

$$1\ \text{MeV} = 1.60 \times 10^{-13}\ \text{J} \qquad 1\ \text{GeV} = 1000\ \text{MeV}$$

$$1\ \text{MeV}/c^2 = \frac{1.60 \times 10^{-13}\ \text{J}}{(3.00 \times 10^{8}\ \text{m/s})^2} \approx 1.78 \times 10^{-30}\ \text{kg}$$

MeV and GeV measure energy. MeV/c^2 and GeV/c^2 measure mass.

EXAMPLE: A DECREASE IN TOTAL REST MASS

$$\text{Mass decrease} = 2.50 \times 10^{-30}\ \text{kg};\ c = 3.00 \times 10^{8}\ \text{m/s}$$

$$E_{\text{released}} = (2.50 \times 10^{-30})(3.00 \times 10^{8})^2$$

$$E_{\text{released}} = 2.25 \times 10^{-13}\ \text{J} = \frac{2.25 \times 10^{-13}}{1.60 \times 10^{-13}}\ \text{MeV} \approx 1.41\ \text{MeV}$$

If the products instead have greater total rest mass, energy must be supplied.

Binding-energy connection: a bound nucleus has less mass than its separated protons and neutrons. Energy is needed to separate them; the same amount is released when that nucleus forms from them.

Source: Pearson IAL Physics, Unit 4 p. 31, points 111-112 and 118-119.

Course lesson numbering. Binding-energy calculations are developed further in Unit 5.