Unit 6

Answers: Atomic Structure

Quick checks

1 b If no atom is made or destroyed in a reaction, and the atoms are only rearranged, the total mass before and after must be the same. The other postulates are true parts of the theory, but they explain other things (constant and multiple proportions).

2 c Isotopes are atoms of the same element (the same number of protons) with different numbers of neutrons, so different masses. That breaks the idea that every atom of an element has the same mass.

3 c If the particles were the same whatever gas or metal they came from, they must be a part of all atoms. The rays bend toward the positive plate, so they are negative, and they bend in a magnetic field, so they are particles, not light.

4 a If nearly every alpha particle passes through without being turned, it met nothing in its way: most of each atom it crossed was empty. The rare large deflections show that the nucleus is small, heavy and positive.

5 b An electron going round in a circle is always changing direction, so it is accelerating, and an accelerating charge radiates energy. Losing energy, it would spiral inward. Rutherford's model had no answer to this; Bohr's did.

6 c In a stationary orbit it gives out nothing. Jumping inward, from higher to lower energy, it gives out the difference as light; jumping outward it must take energy in.

7 b The same number of protons makes them the same element (chlorine), and different numbers of neutrons make their mass numbers different (35 and 37): isotopes.

8 c Sodium-23 has $23 - 11 = 12$ neutrons and magnesium-24 has $24 - 12 = 12$: the same number of neutrons, different elements. Argon-40 and calcium-40 are isobars; the carbons and the hydrogens are isotopes.

1 a. **c** In a chemical reaction only the outer electrons are involved and atoms are never split, so the atom is still the smallest unit of chemistry. The other three were modified by the discovery of subatomic particles, isotopes and isobars.

1 b. **c** Chadwick showed that the radiation from beryllium hit by alpha particles was a stream of neutral particles with about a proton's mass: neutrons.

1 c. **b** Only a tiny, heavy, strongly charged center could turn a fast alpha particle right round, and only a few hit it because it is so small. "Most of the atom is empty space" is shown by the alpha particles that went straight through.

1 d. **b** Bohr's rule is $mvr = \frac{nh}{2\pi}$, with $n = 1, 2, 3\ldots$: angular momentum comes in whole-number steps of $\frac{h}{2\pi}$.

1 e. **b** They have the same mass number, 40, but different atomic numbers, 18 and 20: isobars. (Their neutron numbers, 22 and 20, are different too, so they aren't isotones.)

2 a. A proton carries a charge of $+1.602 \times 10^{-19}$ C and an electron exactly -1.602×10^{-19} C. A neutral atom has as many electrons as protons, and neutrons have no charge, so the positive and negative charges cancel exactly and the atom has no net charge.

2 b. The nucleus holds the protons and neutrons, each with a mass of about 1 u. An electron's mass is only about 0.00055 u, 1/1836 of a proton's, so even all the electrons of an atom add very little: in a hydrogen atom the electron is about 0.05% of the mass, and in heavier atoms, with neutrons too, even less. So more than 99.9% of an atom's mass is in its nucleus.

2 c. Chemical properties depend on the number and arrangement of electrons, especially the outer ones. Isotopes have the same atomic number, so the same number of electrons arranged in the same way, and they react in the same way. They differ only in their number of neutrons, which changes their mass but not their chemistry.

3 i.

Atomic number (Z)	Mass number (A)
The number of protons in the nucleus.	The number of protons plus neutrons in the nucleus.
Decides which element the atom is.	Atoms of one element can have different mass numbers (isotopes).
Equals the number of electrons in a neutral atom.	Is nearly the atom's mass in u.
Written at the bottom left of the symbol: $_{17}$.	Written at the top left: ^{35}.

3 ii.

Rutherford's model	Bohr's model
Electrons can revolve in orbits of any size.	Electrons revolve only in certain fixed orbits, with fixed energies.
Says nothing about the electrons' energies.	Each orbit has a definite energy, increasing outward.
An orbiting electron should radiate and fall into the nucleus.	An electron in a stationary orbit does not radiate; energy is given out or taken in only in jumps between orbits.
Can't explain the stability of atoms or line spectra.	Explains the stability of atoms and the line spectrum of hydrogen.

4 a. **Postulates:**

- All matter is made up of tiny indivisible particles called atoms, the smallest unit of an element.
- Atoms of the same element are alike in mass and properties; atoms of different elements are different.
- Atoms combine in simple whole-number ratios to form molecules.
- In chemical reactions atoms keep their identity: they are only rearranged, never created or destroyed.

Modifications:

i. Atoms are made of smaller particles, electrons, protons and neutrons, so they are divisible (though not in chemical reactions).

ii. Atoms of one element can have different masses because they can have different numbers of neutrons: isotopes, such as chlorine-35 and chlorine-37.

4 b. In 1897 J. J. Thomson studied cathode rays, the rays that stream from the cathode of a discharge tube at very low pressure and high voltage. He bent them with electric and magnetic fields: they bent toward the positive plate, so they were negatively charged particles, and from the amount of bending he found their charge-to-mass ratio (today's value is 1.76×10^{11} C/kg). It was the same for every gas and every cathode metal, and far larger than for any ion, so the particles were much lighter than atoms and part of all atoms. They were named electrons.

Properties of cathode rays (any four):

- They travel in straight lines and cast sharp shadows.
- They are deflected toward the positive plate in an electric field, and by a magnetic field: they are negatively charged.
- They make zinc sulphide and glass glow where they strike.
- They produce X-rays when they strike a metal target.
- They can heat thin metal foils and pass through very thin ones.
- Their nature doesn't depend on the gas or the cathode's metal.

4 c. **Experiment:** A beam of alpha particles from a radioactive source in a lead box with a narrow slit was directed at a very thin gold foil. A circular screen coated with zinc sulphide round the foil flashed where each alpha particle struck, and the flashes were counted through a microscope at different angles. (Diagram: the lead box and source, the beam, the gold foil, the circular zinc sulphide screen, the microscope, and paths: most straight through, a few bent, one or two bouncing back, as in Practical 12.)

Observations and conclusions:

- Most alpha particles passed straight through: most of the atom is empty space.
- Some were deflected through small or large angles: the positive charge is concentrated in a small region that repels them.
- A very few bounced back: the positive charge and nearly all the mass are in a tiny, dense nucleus at the center.

4 d. **Postulates:**

- Electrons revolve round the nucleus only in certain fixed circular orbits (stationary orbits or energy levels), K, L, M, N… (n = 1, 2, 3, 4…).
- An electron in a stationary orbit doesn't radiate energy.
- Each orbit has a fixed energy, lowest in the K shell and increasing outward.
- Only orbits in which the angular momentum $mvr = \frac{nh}{2\pi}$ are allowed.
- Energy is given out or taken in only when an electron jumps from one orbit to another: $\Delta E = E_2 - E_1 = h\nu$.

Merit (any one): it explains the stability of atoms; it explains and calculates the line spectrum of hydrogen.

Limitation (any one): it works only for atoms with one electron; it treats the electron as a particle on a fixed path, whereas an electron has no definite path.

4 e. **Isotopes** are atoms of the same element with the same atomic number but different mass numbers, because they have different numbers of neutrons (for example ${}^{12}_{6}$, ${}^{13}_{6}$, ${}^{14}_{6}$).

Properties: the same chemical properties (same electrons); slightly different physical properties (density, boiling point, rate of diffusion); some are stable and some radioactive; they occupy the same place in the periodic table.

Uses (any three): carbon-14 for dating old objects; cobalt-60 for treating cancer and sterilizing equipment; iodine-131 for thyroid diseases; uranium-235 as nuclear fuel; heavy water (deuterium) in nuclear reactors.

5 a.

i. Al: 13 protons, $27 - 13 = 14$ neutrons, 13 electrons.

ii. Fe: 26 protons, $56 - 26 = 30$ neutrons, 26 electrons.

iii. Mg^{2+}: 12 protons, 12 neutrons, $12 - 2 = 10$ electrons.

iv. O^{2-}: 8 protons, 8 neutrons, $8 + 2 = 10$ electrons.

5 b. $Z = 15$, $A = 15 + 16 = 31$. The element with atomic number 15 is phosphorus: ${}^{31}_{15}$.

5 c.

$$\frac{10.013 \times 19.9 + 11.009 \times 80.1}{100} = \frac{199.26 + 881.82}{100} = 10.81$$

10.81. It is nearer 11 than 10 because boron-11 is about four times as common.

5 d.

$$\frac{62.93x + 64.93(100 - x)}{100} = 63.55$$

$$62.93x + 6493 - 64.93x = 6355 \quad \Rightarrow \quad 2x = 138 \quad \Rightarrow \quad x = 69$$

Copper-63 69%, copper-65 31%.

5 e. Potassium-40 and calcium-40 are isobars: the same number of nucleons, but 19 and 20 protons, so they are different elements. Chemical behavior depends on the electrons, and a neutral potassium atom has 19 (2, 8, 8, 1) while calcium has 20 (2, 8, 8, 2). Potassium gives up one electron and forms K^{+}; calcium gives up two and forms Ca^{2+}. Equal mass says nothing about chemistry; it is isotopes, with the same number of protons, that behave the same way.