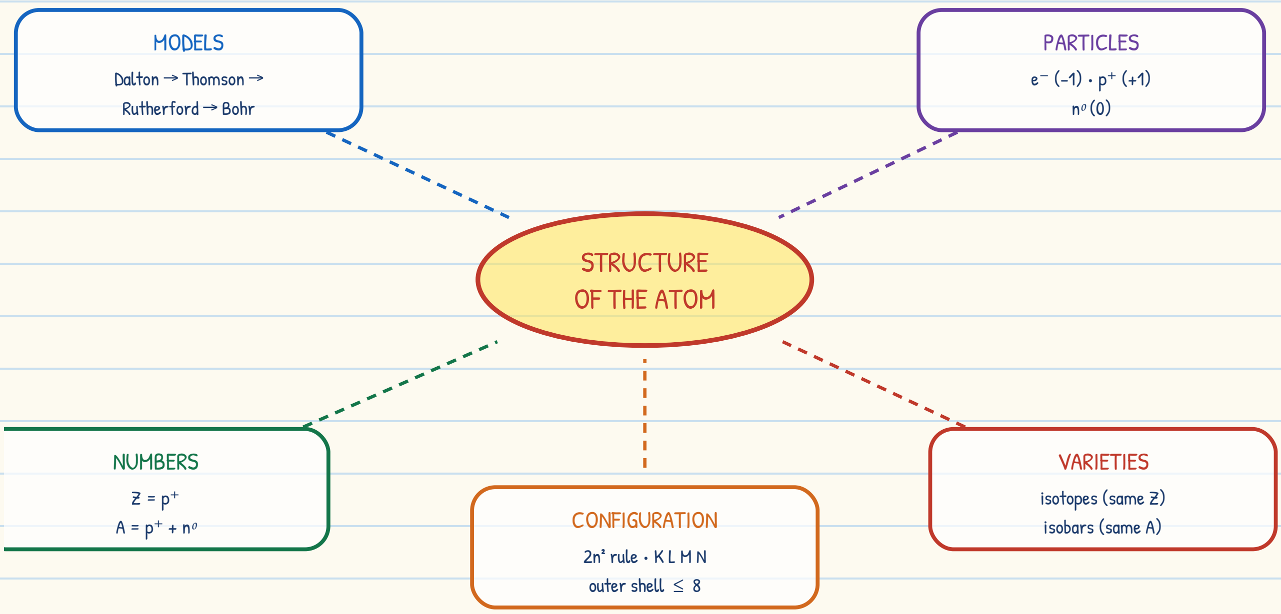
SCIENCE · CLASS 9 · NCERT "EXPLORATION"

# Journey Inside the Atom

CHAPTER 8

*Complete handwritten notes · every diagram, table & flow chart*

*with **all "Pause and Ponder" questions** and **all "Revise, Reflect, Refine" exercises** answered, topic by topic*




Chapter at a glance — the five big ideas

*Think it over (before you begin)*

→ *Are atoms really the smallest, indivisible particles?*

→ *Why do electrons not fall into the nucleus even though protons attract them?*

→ *Why did scientists keep changing the model of the atom again and again?*

*Keep these three questions in mind — the whole chapter is the answer to them.*

## 8.1 Rediscovering the Roots of Atomic Theory

*The question "What is everything made up of?" is more than 2000 years old. Two civilisations — ancient India and ancient Greece — arrived at almost the same answer, purely by thinking.*

*Table A — The earliest ideas about matter*

| Thinker | Place / Time | What was proposed |
|---|---|---|
| **Acharya Kanada** | India, ~6th cent. BCE | Divide matter (dravya) again and again → you reach the smallest indivisible particle, the **parmanu**. It is infinitely small and cannot be sensed. Parmanus join to form **dyads** (2) and **triads** (3), and these build the whole universe. Recorded in the Vaisesika Sutras. Limitation: it did not state in what proportion parmanus combine. |
| **Leucippus & Democritus** | Greece, ~5th cent. BCE | Same idea — indivisible particles called **atomos** (Greek atomos = "that which cannot be cut"). This is where the word **atom** comes from. |
| **John Dalton** | England, 1808 | The **first scientific** (experiment-based) atomic theory: all matter is made of tiny indivisible particles called **atoms**, which are the fundamental building blocks of matter. |

KEY The idea of the atom began as an **imaginative / philosophical** idea, not from experiments. Dalton was the first to base it on **scientific experiments** — that is why his theory became the starting point of modern atomic structure.

After Dalton, three questions drove the next 100 years of science:

- → What are atoms made up of?
- → What would an atom look like if we could see it?
- → What makes the atoms of one element different from another?

## 8.2 A Short Historical Journey Through Atomic Models

Till the late $19^{th}$ century everyone believed the atom was the smallest, indivisible unit. Then came the discovery of radioactivity — certain elements emit invisible energy and particles called **radiation**. If something is coming out of the atom, the atom must have parts inside!

MODEL A **model** is a simple picture scientists build to explain their observations. When a new experiment does not fit, the model is changed or replaced. Old models are not "useless" — they show how science moves forward, one step at a time.

### » Discovery of the electron — Thomson's cathode ray experiment (1897)

J. J. Thomson studied the **conduction of electricity through gases at very low pressure**. He took a glass tube with two electrodes and applied a high voltage.

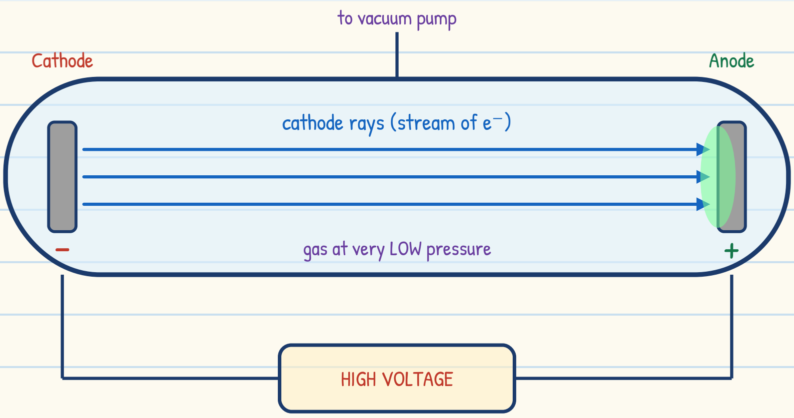



Fig. 8.1 — Line diagram of a cathode ray tube

***Observation:*** *rays travelled from the* ***cathode (−)*** *to the* ***anode (+)****. These were named* ***cathode rays****.*

***On applying electric and magnetic fields:*** *the rays bent — proving they are streams of negatively charged particles with a mass far smaller than an atom. These particles were later named* ***electrons****.*

WHY IT MATTERS *The nature of cathode rays did* ***not*** *depend on the material of the cathode or on the gas filled in the tube. Same rays, every time. ⇒ Electrons are a fundamental part of* ***every*** *atom of* ***every*** *element.*

*Charge of an electron =* $\mathbf{-1.602 \times 10^{-19}}$ **C***, taken as* **−1** *by convention for convenience.*

*Meet a Scientist — J. J. Thomson*
*Discovered the* ***electron*** *— the first subatomic particle ever identified, and a part of every atom.* ***Nobel Prize in Physics, 1906****, for his study of electrical conduction in gases. As head of the famous* ***Cavendish Laboratory****, Cambridge, he guided many scientists — including Ernest Rutherford.*

## » 8.2.1 Thomson's Model of an Atom

*Thomson faced a puzzle: electrons are negative, but atoms are* ***neutral*** *— so where is the positive charge? His answer: the atom is a sphere of positive charge with electrons stuck all through it.*

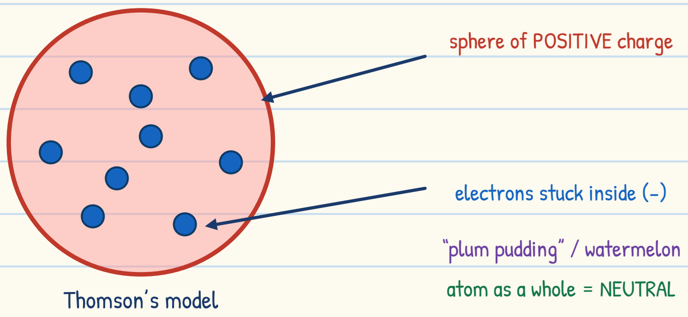



Fig. 8.2 — Thomson's "plum pudding" model of the atom

### *The two famous analogies*

| Analogy | Positive charge | Electrons |
|---|---|---|
| **Plum pudding** | *the pudding* | *the plums embedded in it* |
| **Watermelon** (Fig. 8.3) | *the red pulp* | *the seeds spread throughout* |

**Note**

*Atoms have* ***no colour****. The colours in all these diagrams (red nucleus, blue electrons) are only for illustration.*

### Score card of Thomson's model

✔ **Explained:** the atom is electrically neutral — total (+) charge = total (–) charge.

✘ **Failed:** could not explain the results of the gold foil experiment (next topic).

## Pause and Ponder Q1 - Q3

1 **Suppose you made your own 'atom' as Thomson described, using clay for the positive charge and small beads for the electrons spread through it. What will happen if (i) the positive charge on the clay is less than the total negative charge of the beads? (ii) by mistake, the clay itself carries a bit of negative charge — would your model still be a neutral atom?**

*Ans.* **(i)** The negative charge would no longer be cancelled. The model would carry a **net negative charge** — so it would represent a **negative ion (anion)**, not a neutral atom.
**(ii)** No. If the clay is also negative, there is nothing positive left to balance the beads. The whole model becomes negatively charged and **breaks the basic requirement of Thomson's model** — that a positive sphere must exactly balance the embedded electrons.

**2** **Could an orange or a lemon, which also contain seeds inside soft pulp, be a good comparison? In what ways does it match Thomson's idea and where does it fall short?**

*Ans.* **Where it matches:** *it is roughly spherical, the seeds (electrons) are* **inside** *a soft bulk (positive matter), and the seeds are much smaller than the fruit — just as electrons are far lighter than the atom.*

**Where it falls short:**

- *The pulp is divided into* **segments***, but Thomson's positive charge is* **continuous and uniform***.*
- *The seeds sit* **near the centre / in rows***, not spread evenly throughout.*
- *The peel forms a definite boundary; an atom has no such "skin".*
- *The seeds carry no charge, so the neutrality idea is not modelled at all.*

**3** **Why did Thomson conclude that electrons are present in all atoms?**

*Ans.* Because the **properties of cathode rays were always the same** *— the same negative charge and the same (very small) mass — no matter* **which metal** *was used as the cathode or* **which gas** *was filled in the tube. If a particle can be pulled out of every material, it must already be present in every atom. Hence the electron is a universal constituent of all atoms.*

## » 8.2.2 Testing Thomson's Model — The Gold Foil Experiment (1911)

*Geiger and Marsden, working under* **Ernest Rutherford***, fired a narrow beam of* ***α-particles*** *at an extremely thin sheet of gold foil.*

DEF **α (alpha) particle** *— a tiny, fast,* **positively charged** *particle emitted by radioactive elements. It is actually the* **nucleus of a helium atom***: 2 protons + 2 neutrons (charge +2, mass 4 u).* **Scattering** *— deflection of a particle from its straight path. That is why this is also called the* **α-ray scattering experiment***.*

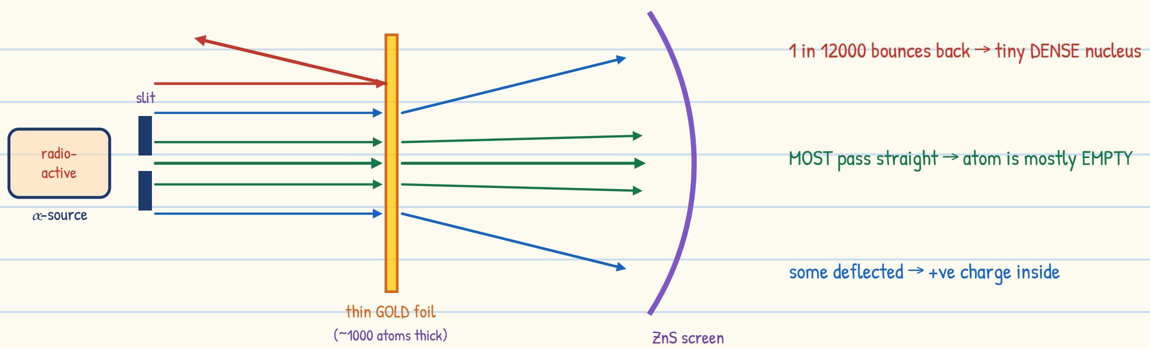



Fig. 8.4 — Schematic view of the gold foil (α-scattering) experiment

*Table B — Observation → Conclusion (the heart of this chapter)*

| Observation | Expected (Thomson) | Conclusion drawn |
| --- | --- | --- |
| **Most** $\alpha$-particles passed straight through, undeflected | same | Most of the atom is **empty space** |
| **Some** were deflected through small angles | only very slight deflection | There is a **positive charge** inside the atom that repels them, but it occupies a very small volume |
| **Very few** (about 1 in 12000) bounced straight back | **never expected!** | All the positive charge and almost all the mass are packed into an extremely small, **dense centre — the nucleus** |

FAMOUS LINE Rutherford said it was "as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

**Thomson's model failed here:** if the positive charge were spread thinly over the whole atom, the repulsive push at any point would be far too weak to turn back a heavy, fast $\alpha$-particle.

*Think as a Scientist*

**What if the gold foil were made thicker?**

A thicker foil = many more layers of atoms = many more nuclei in the path. So the chance of a close encounter rises: **fewer** $\alpha$-particles would pass straight through, **many more** would be deflected, and more would be scattered through large angles or bounce back. Multiple scattering would also blur the pattern on the screen, so the result would be harder to interpret — this is exactly why Rutherford insisted on an extremely thin foil.

## Exercise Q1 Revise, Reflect, Refine

**① Choose the correct options and explain the reason for the correct and incorrect options in the context of Rutherford's gold foil experiment.**

Ans. **Correct: (ii) and (iii). Incorrect: (i) and (iv).**

- **(i) Showed the existence of neutrons — INCORRECT.** *$\alpha$-particles are positive and are deflected by charge. A neutral particle produces no such effect. The neutron was discovered much later, by* **Chadwick in 1932**.
- **(ii) Disproved the plum pudding model and led to the nucleus — CORRECT.** *A uniformly spread positive charge can never turn a fast $\alpha$-particle back; a concentrated positive centre can.*
- **(iii) Large deflection of a few $\alpha$-particles ⇒ mass and positive charge packed in a tiny centre — CORRECT.** *Only something very heavy and highly positively charged can reverse the $\alpha$-particle; and since only a few were affected, that region must be very small.*
- **(iv) Showed how electrons move — INCORRECT.** *Electrons are ~7300 times lighter than an $\alpha$-particle, so they cannot deflect it noticeably. The experiment gave* **no information at all** *about electron motion; that came later from Bohr.*

## » A. Rutherford's Model of the Atom (the nuclear model)

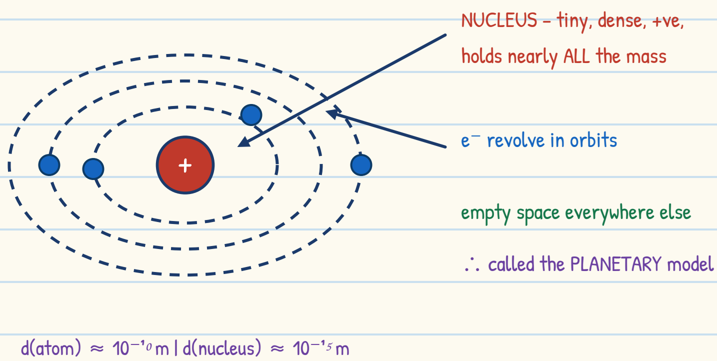
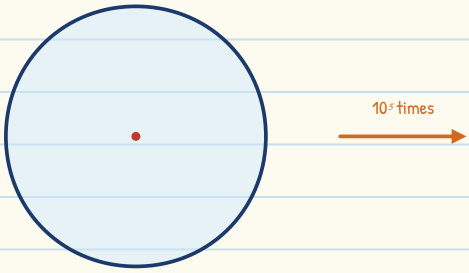



Fig. 8.5 — The planetary (nuclear) model suggested by Rutherford

- ★ ***Most of the atom is empty space*** *— because most $\alpha$-particles went straight through.*
- ★ *The* ***nucleus*** *is a very small,* ***dense*** *centre carrying* ***all the positive charge*** *and* ***almost all the mass*** *of the atom.*
- ★ ***Electrons revolve around the nucleus***, *like planets around the Sun ⇒ the planetary model.*




d(atom) ≈ $10^{-10}$ m

d(nucleus) ≈ $10^{-15}$ m

∴ nucleus is 1,00,000× smaller

⇒ atom is 99.99% EMPTY SPACE

ATOM = cricket ground (100 m)
nucleus = 1 peppercorn at centre

How ridiculously small the nucleus is

*Ready to Go Beyond — a nice calculation*

*How many atoms are stacked across a sheet of paper 0.1 mm thick?*

*Thickness = 0.1 mm =* $\mathbf{10^{-4}}$ **m**, *diameter of one atom ≈* $\mathbf{10^{-10}}$ **m**

*Number of atoms =* $10^{-4} \div 10^{-10}$ = $\mathbf{10^6}$ **= about one million atoms!**

## Pause and Ponder Q4 - Q6

4 **What do you think would happen if α-particles were replaced with negatively charged particles in Rutherford's gold foil experiment?**

*Ans. The force would flip from* **repulsion to attraction**. *Negative particles (e.g. electrons / β-particles) would be* **pulled towards the positive nucleus** *instead of being pushed away, so they would bend inwards and none would bounce straight back the way α-particles did.*
*Also, being about* **7300 times lighter** *than an α-particle, they would be knocked about easily — even by the electrons of the gold atoms — giving scattering in all directions. The clean "most go straight, a few rebound" pattern would be lost, and the nucleus would be much harder to detect.*

5 **Rutherford found that a few α-particles bounced back sharply. How does this single surprising result completely rule out Thomson's 'plum pudding model'?**

*Ans. To reverse a fast, heavy, positive α-particle you need* **a huge repulsive force** *acting over a* **very short distance**, *i.e. a target that is (a)* **highly positively charged**, *(b)* **very massive** *and (c)* **extremely concentrated**.
*In the plum pudding model the positive charge is* **smeared thinly over the whole atom**, *so at any point the charge — and hence the repulsion — is tiny. Such an atom could* **never** *push an α-particle back; at most it could nudge it slightly.*
*So even* **one** *rebound is fatal to the model: in science, a single reproducible observation that a theory cannot explain is enough to reject it.*

**6** **If you could ask Rutherford one question about his work, what would it be?**

*Ans.* (Open-ended — your own question is valid. Sample answers:)

- "When the first α-particle bounced back, did you think it was a mistake in the apparatus rather than a discovery?"
- "If the nucleus is so tiny, what holds it together against the repulsion of all those protons?"
- "Your model could not explain why the atom does not collapse — did that trouble you?"

*Tip: a good scientific question asks about* **evidence**, **limitation** *or* **next step** *— not just a fact.*

## Exercise Q4 Revise, Reflect, Refine

**4** **What conclusion did Rutherford draw about the position and characteristics of the atom's positively charged part, based on the few alpha particles that bounced back or were deflected at large angles?**

*Ans.* **Position:** the positive charge is **not spread over the whole atom** — it is concentrated at the **centre**, in a region he named the **nucleus**.

**Characteristics:**

- **Extremely small** — about $10^5$ (one lakh) times smaller than the atom ($d_{nucleus} \approx 10^{-15}$ m vs $d_{atom} \approx 10^{-10}$ m).
- **Positively charged** — it repelled the positive α-particles.
- **Very dense and heavy** — it carries almost the **entire mass** of the atom, which is why it could turn a heavy α-particle back instead of being pushed aside.
- The rest of the atom, where the electrons move, is essentially **empty space**.

## » B. Limitation of Rutherford's Model — the stability problem

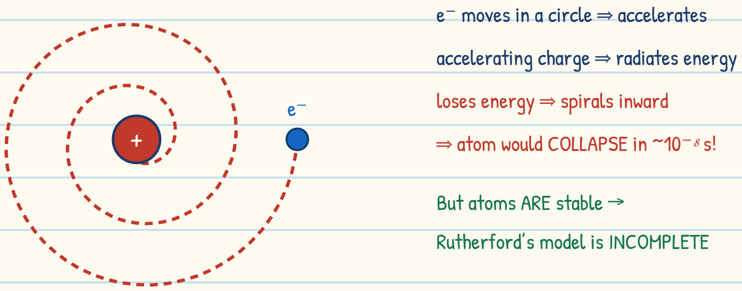



Fig. 8.6 – Spiral path of a charged particle that keeps losing energy

THE PROBLEM A particle moving in a circle is constantly changing direction ⇒ it is **accelerating** (Chapter 4, Describing Motion Around Us). An accelerating **charged** particle must radiate energy. An electron that keeps losing energy would **spiral inward** and crash into the nucleus — so every atom would collapse in a fraction of a second. **But atoms are stable!** Hence Rutherford's model was incomplete.

## » C. Discovery of the Proton

- Rutherford showed the nucleus is positive; that charge comes from particles called **protons**.
- A proton is **much heavier** than an electron, and carries a charge **equal and opposite** to it (+1).
- For an atom to be electrically neutral: number of protons = number of electrons.

$$\text{no. of } p^+ = \text{no. of } e^- \Rightarrow \text{atom is NEUTRAL}$$

*Examples — helium: 2 $p^+$, 2 $e^-$ | sodium: 11 $p^+$, 11 $e^-$. In each case total (+) = total (−), so the atom is neutral. This is true for **all** atoms.*

*Meet a Scientist – Ernest Rutherford*

Born in **New Zealand**; came to Cambridge to work with J. J. Thomson and later became the **"Father of Nuclear Physics"**. He discovered the atomic **nucleus**, explained radioactive decay (**Nobel Prize in Chemistry, 1908**) and proposed the nuclear model in **1911**. His portrait appears on New Zealand's $100 note.

### Pause and Ponder

Q7 — Assertion & Reason

7 **Assertion (A): Rutherford concluded that most of the mass of an atom is concentrated in a small region at the centre called the nucleus.**

**Reason (R): According to Thomson's model, electrons are embedded in a uniformly distributed positive charge sphere.**

Ans. **Correct option: (ii) — Both A and R are true, but R is not the correct explanation of A.**

- **A is true:** the large-angle deflection and rebound of $\alpha$-particles proved that the mass and positive charge sit in a tiny central nucleus.
- **R is true:** that is a correct statement of Thomson's model.
- **But R does not explain A:** R only describes an older, different model. Rutherford's conclusion came from the **observations of the gold foil experiment**, not from Thomson's description. In fact the experiment contradicted R.

## » 8.2.3 Bohr's Model of the Atom (1913)

To rescue the atom from collapsing, **Niels Bohr** made a bold proposal.

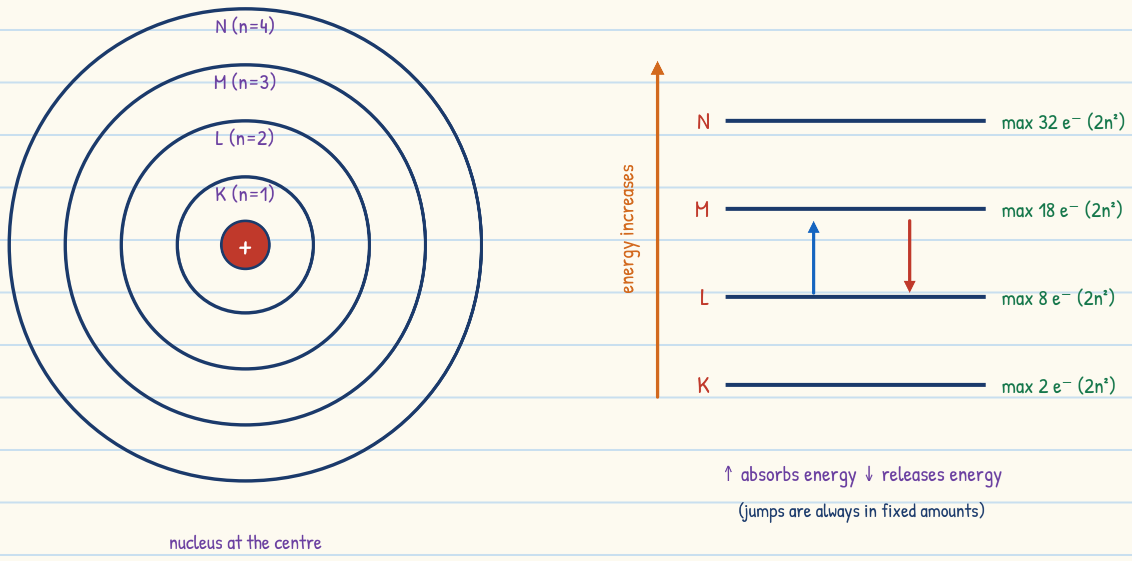



Fig. 8.7 — Energy levels (shells) in an atom, and jumps between them

### Bohr's postulates

- ★ Electrons do **not** move randomly. They revolve in **fixed circular paths** called stationary states / orbits / shells.
- ★ Each shell has a **definite amount of energy** ⇒ shells are also called **energy levels**.
- ★ Shells are named **K, L, M, N ...** or numbered **$n$ = 1, 2, 3, 4 ...**
- ★ Electrons can exist **only** in these allowed shells — **never in between** them.
- ★ While moving in a fixed shell, an electron does **not** lose energy. ← this is the whole point of the model.
- ★ **K ($n$ = 1)** is nearest the nucleus and has the **least** energy. Energy **increases** as you move outward: $E_K < E_L < E_M < E_N$.
- ★ An electron moves from one shell to another only by **absorbing** (jump outward) or **releasing** (fall inward) a **fixed** amount of energy = the difference between the two levels.
- ★ Each shell can hold only a **certain maximum number** of electrons (see 8.7).

HOW STABILITY IS EXPLAINED In Bohr's model the electron still moves in a circle — but he **postulated** that in a **stationary state** its energy stays constant even though it is moving. No energy is radiated ⇒ no spiralling in ⇒ **the atom is stable.**

*Threads of Curiosity – why K, L, M, N and not A, B, C, D?*

*The names come from early **X-ray** work by **Charles Barkla**, who called the first X-ray line he saw "K". He deliberately did not start at A, leaving room in case an earlier series was discovered — none ever was. Bohr borrowed the same lettering for atomic shells.*

*Meet a Scientist – Niels Bohr*

*Professor of physics at **Copenhagen University, Denmark**. He was troubled that older models could not explain why electrons stay around the nucleus without collapsing into it. His explanation of atomic structure won him the **Nobel Prize in Physics, 1922**.*

*Next level up*

*Even Bohr's model was later found to have limitations. It was replaced by the **quantum mechanical model**, in which electrons do not follow neat fixed paths at all but exist as **"electron clouds"** — regions where an electron is most likely to be found. You will study this in higher classes.*

## Exercise Q2, Q6 & Q10 on Bohr's model

**2 Which of the following statements are correct or incorrect according to Bohr's atomic model? Give a reason for each.**

*Ans.*

- ***(i) Electrons lose energy in fixed orbits and slowly fall into the nucleus — INCORRECT.*** *This is exactly the flaw of Rutherford's model. Bohr postulated that in a stationary state the electron does **not** radiate energy, so it never spirals in.*
- ***(ii) Electrons can exist anywhere around the nucleus with no fixed energy — INCORRECT.*** *Energy is **quantised**: an electron in a given shell has one definite energy value, not any arbitrary value.*
- ***(iii) Electrons revolve in orbits of fixed energy without losing energy — CORRECT.*** *This is Bohr's central postulate of **stationary states**, and it is what explains the stability of the atom.*
- ***(iv) Electrons can be found between energy levels — INCORRECT.*** *Only certain orbits are permitted. The space between two shells is a **forbidden region**; an electron crossing over must jump in one go by absorbing or emitting exactly the energy difference.*

**6** **Electrons move around the nucleus in orbits. Why do they not fly away from the atom? Explain what keeps them attracted to the nucleus.**

*Ans.* Electrons carry a **negative** charge and the nucleus carries a **positive** charge (protons). The **electrostatic force of attraction** between opposite charges pulls the electron towards the nucleus.

This inward pull acts as the **centripetal force** that keeps the electron moving in its circular shell — exactly as gravity keeps a planet in orbit around the Sun. The electron's motion balances the pull: it neither flies off nor falls in.

To actually escape, an electron must be supplied energy at least equal to its **binding (ionisation) energy** — which is why atoms hold on to their electrons and matter stays intact.

**10** **Both Rutherford's and Bohr's models have electrons orbiting the nucleus. Why did Rutherford's model fail to explain atomic stability, while Bohr's model succeeded?**

*Ans.* **Rutherford failed because** he applied ordinary (classical) physics: an electron revolving in a circle is continuously **accelerating**; an accelerating charge **must radiate energy**; losing energy it would spiral inward and hit the nucleus almost instantly (~$10^{-8}$ s) — the atom would collapse. His model gave **no reason** why this does not happen.

**Bohr succeeded because** he added a new rule: only certain **fixed orbits (stationary states)** are allowed, and **in these orbits the electron does not radiate energy at all**. Energy can be lost or gained only in fixed jumps between levels — never continuously. With no continuous energy loss, there is no inward spiral, and the atom is stable.

*In short: same picture, but Bohr* ***quantised*** *it.*

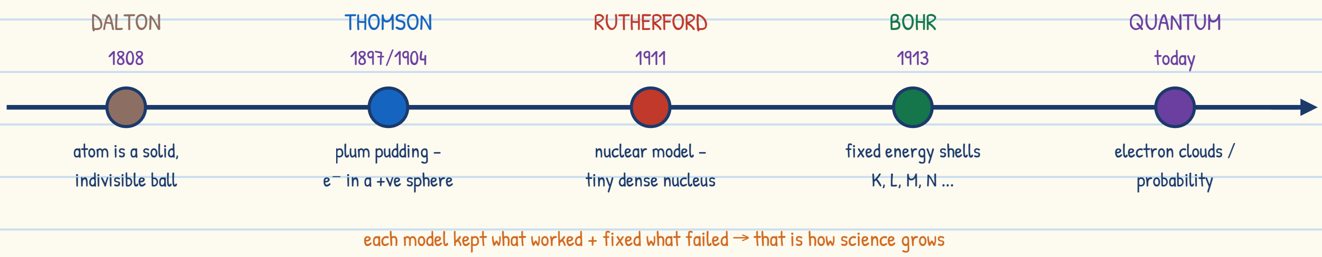



Fig. 8.16 — Journey of the development of atomic models

Exercise Q5 chronological order

**5** **Explain and arrange the statements in the correct chronological order to show how atomic models evolved.**

*Ans.* **Correct order: (iv) → (ii) → (iii) → (i)**

1. **(iv) Dalton (1808)** — the atom is an indivisible, solid particle; the first scientific theory of matter.
2. **(ii) Thomson (1904)** — after discovering the electron, the atom became a 'plum pudding': electrons embedded in a sphere of positive charge. The atom is no longer indivisible.
3. **(iii) Rutherford (1911)** — the gold foil experiment showed a dense central **nucleus** with empty space around it.
4. **(i) Bohr (1913)** — electrons move in **fixed orbits of definite energy**, which finally explained why the atom does not collapse.

Each model kept what was right in the previous one and repaired what it could not explain.

## 8.3 What Components Contribute to the Mass of an Atom?

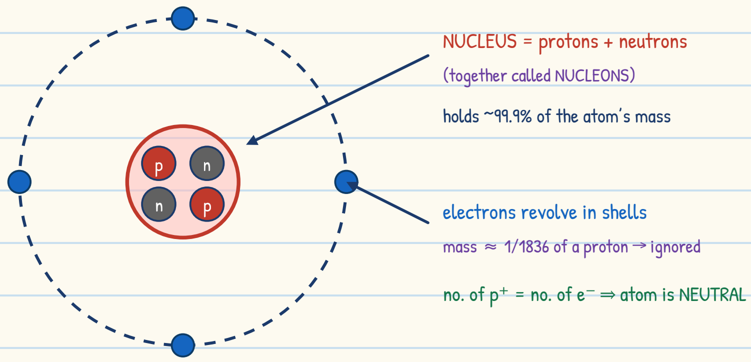
Rutherford showed that nearly all the mass sits in the nucleus; electrons are so light that their mass can be ignored. But a puzzle remained:

THE PUZZLE Hydrogen has **1 proton**; helium has **2 protons**. So helium should be **twice** as heavy as hydrogen — but it is actually about **four times** heavier! Is there something else in the nucleus that adds **mass without adding charge**?

### » 8.3.1 Discovery of the Neutron (1932)

**James Chadwick**, a student of Rutherford, found a new subatomic particle with a mass nearly equal to that of a proton but with **no charge** — the **neutron**, symbol **n**.

- → Neutrons are present in the nucleus of **all atoms except ordinary hydrogen** ($^{1}_{1}H$).
- → Mass of an atom comes mainly from **protons + neutrons** packed in the nucleus.
- → This is why atoms are heavier than the total mass of their protons alone.




The three subatomic particles and where they live

*Table 8.1 — Symbols and relative charges of subatomic particles*

| S. No. | Subatomic particle | Symbol | Relative charge | Relative mass (u) | Location |
|---|---|---|---|---|---|
| 1. | Electron | $e^-$ | −1 | ≈ 1/1836 (negligible) | outside nucleus, in shells |
| 2. | Proton | $p^+$ | +1 | 1 | inside nucleus |
| 3. | Neutron | $n^0$ | 0 | 1 | inside nucleus |

*The last two columns are extra — they are not in the NCERT table but make the table far more useful for questions.*

## Why do heavier atoms need more neutrons?

| Element | Protons | Neutrons | Pattern |
|---|---|---|---|
| Carbon | 6 | 6 | light atoms: $p^+ \approx n^0$ |
| Oxygen | 8 | 8 | |
| Iron | 26 | 30 | **heavy atoms: $n^0 > p^+$** |
| Uranium | 92 | 146 | |

*Threads of Curiosity — why don't the protons push each other apart?*

Every proton repels every other proton (all are positive). Neutrons help in two ways:

- being neutral, they **sit between protons and increase the distance** between them, weakening the repulsion;
- they **strengthen the nuclear force** — the very strong, very short-range force that binds all nucleons together.

That is why heavy nuclei need **many extra neutrons** to stay bound.

### Meet a Scientist – James Chadwick

Working under Rutherford at the **Cavendish Laboratory**, Cambridge, he discovered the **neutron in 1932** — solving the atomic-mass puzzle. **Nobel Prize in Physics, 1935**. Because neutrons are uncharged they can slip into nuclei easily, which led to artificial radioactive elements and to the splitting of uranium — the beginning of the '**atomic age**', giving both nuclear power and nuclear weapons.

### What if ...

an atom had **no empty space**? Matter would become unimaginably dense — the entire Earth would shrink to a ball a few hundred metres across, and everyday objects would be billions of times heavier. (This actually happens in **neutron stars**: a teaspoon would weigh ~1 billion tonnes.)

### India's Scientific Contributions

The **Bhabha Atomic Research Centre (BARC)**, Mumbai (Fig. 8.8), runs advanced **neutron-scattering** experiments using reactors such as **Dhruva**. These reveal the inner structure of superconductors, battery electrodes and drug molecules — helping build better medicines, energy storage and industrial alloys in India.

## Exercise Q7 Assertion & Reason

7 **Assertion (A): The discovery of subatomic particles helped in understanding the atomic structure.**

**Reason (R): The number of electrons is equal to the number of protons in an atom.**

Ans. **Correct option: (ii) — Both A and R are true, but R is not the correct explanation of A.**

- **A is true:** each discovery — electron (1897), proton, neutron (1932) — revealed one more piece of the atom and forced a better model.
- **R is true:** in a neutral atom the number of electrons does equal the number of protons.
- **R does not explain A:** R states only one particular fact about a neutral atom (its charge balance). It does not explain why discovering the particles improved our understanding of atomic structure. It is a **consequence** of the discoveries, not the reason for them.

*Quick recap — who discovered what*

| Particle | Discovered by | Year | Key experiment / idea |
|---|---|---|---|
| Electron | J. J. Thomson | 1897 | Cathode ray tube — rays bent by fields |
| Nucleus & Proton | E. Rutherford | 1911 | $\alpha$-particle scattering from gold foil |
| Neutron | J. Chadwick | 1932 | Neutral particle explaining the extra mass |

## 8.4 Symbols of Elements

By 1869 scientists knew about **69 elements**. Today **118** elements are known — some of them made artificially — and the search continues.

- **1803 — John Dalton** gave the first **pictorial symbols** (circles with dots, lines, letters) for the known elements (Fig. 8.9). They were hard to draw and remember.
- **1813 — J. J. Berzelius** suggested using **letters from the Latin names** → alphabetic symbols.
- **Today — IUPAC** (International Union of Pure and Applied Chemistry) approves the names and symbols of all elements.

### Rules for writing symbols

*Table C — IUPAC rules with examples*

| Rule | Examples |
|---|---|
| Many symbols are the **first letter** or the **first two letters** of the name | Hydrogen → **H**, Carbon → **C**, Aluminium → **Al** |
| The first letter is **always CAPITAL**, the second (if any) is **always small** | **Al** not AL; **Co** not CO; **Cl** not CL (CO would mean carbon + oxygen!) |
| Sometimes the second letter is taken from **elsewhere** in the name, not the 2nd letter | Chlorine → **Cl**, Zinc → **Zn**, Magnesium → **Mg** |
| Some come from **Latin, Greek or German** names | Iron → **Fe** (ferrum), Mercury → **Hg** (hydrargyros), Tungsten → **W** (wolfram) |

*Table 8.2 — Common elements and their symbols (learn these by heart)*

| Element | Symbol | Element | Symbol | Element | Symbol |
|---|---|---|---|---|---|
| Aluminium | Al | Copper (Cuprum) | **Cu** | Nitrogen | N |
| Argon | Ar | Fluorine | F | Oxygen | O |
| Barium | Ba | Gold (Aurum) | **Au** | Potassium (Kalium) | **K** |
| Boron | B | Hydrogen | H | Silicon | Si |
| Bromine | Br | Iodine | I | Silver (Argentum) | **Ag** |
| Calcium | Ca | Iron (Ferrum) | **Fe** | Sodium (Natrium) | **Na** |
| Carbon | C | Lead (Plumbum) | **Pb** | Sulfur | S |
| Chlorine | Cl | Magnesium | Mg | Uranium | U |
| Cobalt | Co | Neon | Ne | Zinc | Zn |

**Red symbols** = the ones that do **not** match the English name — these are the most commonly asked in exams.

Pause and Ponder Q8 - Q9

**8** **Imagine you are a scientist who has discovered a new element. Name this element after yourself and justify that the symbol you have chosen follows the IUPAC rules.**

Ans. (Sample answer — use your own name.)

Name: **Mayankium** → Symbol: **My**

**Justification against each IUPAC rule:**

- The symbol is short — **two letters**, taken from the element's name.
- The **first letter M is capital** and the **second letter y is small** — written **My**, never MY or my.
- It is **not already used** by any of the 118 known elements (Mg, Mn, Mo, Mt, Md are taken — My is free), so there is no confusion.
- The name ends in **"-ium"**, the ending IUPAC uses for newly discovered metallic elements.
- It is easy to pronounce and can be written the same way in every language.

Note: in real practice IUPAC does not allow an element to be named after a living discoverer — names usually honour a scientist, place, mineral, mythological figure or property.

**9** **What problems could arise if every scientist used different symbols for the same element?**

Ans.

- **Confusion in formulae and equations** — the same formula would mean different compounds to different people.
- **Experiments could not be repeated**, because nobody would be sure which substance was used.
- **Language barriers would return** — a symbol is understood worldwide, a name is not.
- **Dangerous errors** in medicine, industry and trade — e.g. mixing up a harmless and a poisonous substance.
- **Textbooks, research papers and databases** from different countries could not be compared, slowing science down.

That is why the symbols are standardised by **IUPAC** and used identically all over the world.

## 8.5 Atomic Number (Z)

**DEF** ***Atomic number (Z)*** *= the number of* ***protons*** *in the nucleus of an atom. It* ***determines the identity*** *of the element and its chemical behaviour.*

$$Z = \text{number of protons} = \text{number of electrons (in a neutral atom)}$$

→ *Hydrogen: 1 $p^+$, 1 $e^-$ ⇒ $Z = 1$ | Helium: 2 $p^+$, 2 $e^-$ ⇒ $Z = 2$ | Lithium: 3 $p^+$, 4 $n^0$ ⇒ $Z = 3$*

→ *Two elements can never have the same atomic number. Change Z and you change the element itself.*

## 8.6 Mass Number (A)

**DEF** ***Mass number (A)*** *= total number of* ***protons + neutrons*** *in the nucleus. Protons and neutrons together are called* ***nucleons****.*

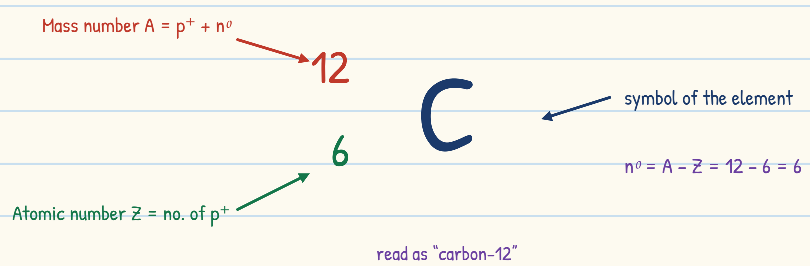
$$A = p^+ + n^0 \quad \Rightarrow \quad n^0 = A - Z$$

*The electron's mass is almost negligible, so it is* ***never*** *counted in the mass number.*

*Table 8.3 — Mass number of some elements*

| Element | Protons ($p^+$) | Neutrons ($n^0$) | Mass number (A) |
|---|---|---|---|
| Hydrogen | 1 | 0 | 1 |
| Helium | 2 | 2 | 4 |
| Lithium | 3 | 4 | 7 |

### Standard notation of an atom




How to read $^{A}_{Z}X$ — mass number on top, atomic number below

*Memory trick*

***A*** *is* ***A****bove and it is the* ***A****tomic* ***mass****-ish number. Z is at the bottom (like the last letter of the alphabet) and counts protons. Neutrons are never written — you always* ***subtract*** *to get them.*

## Pause and Ponder
Q10 – Q13 (numericals)

**(10) An atom with an atomic number of 26 has 56 nucleons. Find its number of electrons, protons and neutrons.**

*Ans.* **Given:** $Z = 26$, nucleons $(A) = 56$

Protons $= Z =$ **26**

Electrons = protons (neutral atom) = **26**

Neutrons $= A - Z = 56 - 26 =$ **30**

The element is **iron (Fe)**, written as $^{56}_{26}Fe$.

**(11) The nucleus of an atom contains 20 protons. If its mass number is 41, find the number of neutrons in it.**

*Ans.* **Given:** $Z = 20$, $A = 41$

Neutrons $= A - Z = 41 - 20 =$ **21**

($Z = 20 \Rightarrow$ the element is calcium, so this is $^{41}_{20}Ca$.)

**(12) An atom has 18 neutrons and an atomic number of 17. What is its mass number?**

*Ans.* **Given:** $n^0 = 18$, $Z = 17$

$A = p^+ + n^0 = 17 + 18 =$ **35**

The element is **chlorine** — $^{35}_{17}Cl$.

**(13) An atom $^{23}A$ has 11 electrons. Find the number of neutrons in it.**

*Ans.* **Given:** $A = 23$, electrons $= 11$

In a neutral atom, protons = electrons $\Rightarrow Z =$ **11**

Neutrons $= A - Z = 23 - 11 =$ **12**

The element is **sodium (Na)** — $^{23}_{11}Na$.

## Exercise Q11, Q12 & Q15
numericals on Z and A

**(11) An atom $^{70}X$ has 31 electrons. How many neutrons are there in its nucleus?**

*Ans.* Electrons $= 31 \Rightarrow$ protons $= 31 \Rightarrow Z =$ **31**; $A = 70$

Neutrons $= A - Z = 70 - 31 =$ **39**

$Z = 31 \Rightarrow$ the element is **gallium (Ga)**.

12 **An atom has 79 protons and a mass number of 197. Calculate (i) the number of neutrons and (ii) the number of electrons.**

Ans. **(i)** Neutrons = A − Z = 197 − 79 = **118**

**(ii)** Electrons = protons = **79** (the atom is neutral)

Z = 79 ⇒ the element is **gold (Au)**, $^{197}_{79}Au$.

15 **In an atom there are 12 protons and 12 neutrons. Now imagine all the electrons are replaced by hypothetical particles with the same charge as an electron but 500 times heavier. What effect will this have on the atom's (i) atomic number, (ii) atomic mass, (iii) mass number, (iv) overall charge?**

Ans. **The atom is magnesium: Z = 12, A = 24, 12 electrons.**

- **(i) Atomic number — no change, Z = 12**. Z counts only **protons**, and the protons were not touched.
- **(ii) Atomic mass — increases noticeably**. Normally 1 electron ≈ 1/1836 u, so 12 electrons ≈ 0.0065 u (ignorable). Now each weighs 500 × 1/1836 ≈ 0.27 u, so 12 of them ≈ **3.3 u**. New atomic mass ≈ 24 + 3.3 ≈ **27.3 u** — electron mass can **no longer be ignored**.
- **(iii) Mass number — no change, A = 24**. Mass number counts only **nucleons** (protons + neutrons), never electrons.
- **(iv) Overall charge — no change, the atom stays neutral (0)**. The new particles carry the **same charge** (−1 each), and 12 negative charges still cancel 12 protons. **Mass changed; charge did not.**

## 8.7 How Are Electrons Distributed in Different Energy Levels?

The rules were given by **Bohr and Bury**:

RULE 1 Maximum number of electrons in a shell = **$2n^2$**, where n is the shell number.

| Shell | n | $2n^2$ | Maximum electrons |
|---|---|---|---|
| K | 1 | $2 \times 1^2$ | **2** |
| L | 2 | $2 \times 2^2$ | **8** |
| M | 3 | $2 \times 3^2$ | **18** |
| N | 4 | $2 \times 4^2$ | **32** |

RULE 2 The **outermost shell** can hold a maximum of **8 electrons** — no matter what $2n^2$ allows. (The first shell can hold only **2**.)

RULE 3 Electrons are filled **step by step from the inside out**: K → L → M → N. A shell is filled only after the one before it is complete.

*Why sodium is 2,8,1 and not 2,9*

The L shell is full at 8 ($2n^2 = 8$), so the $11^{th}$ electron must start a new shell M. And why not 2,8,1 → 2,8,1 only? Because Rule 2 caps the outermost shell at 8, and Rule 3 forbids skipping a shell.

## » 8.7.1 Building Up Atoms — the first eighteen elements

DEF **Electronic configuration** = the distribution of electrons among the various shells of an atom, written as K, L, M, N (e.g. sodium = **2, 8, 1**).

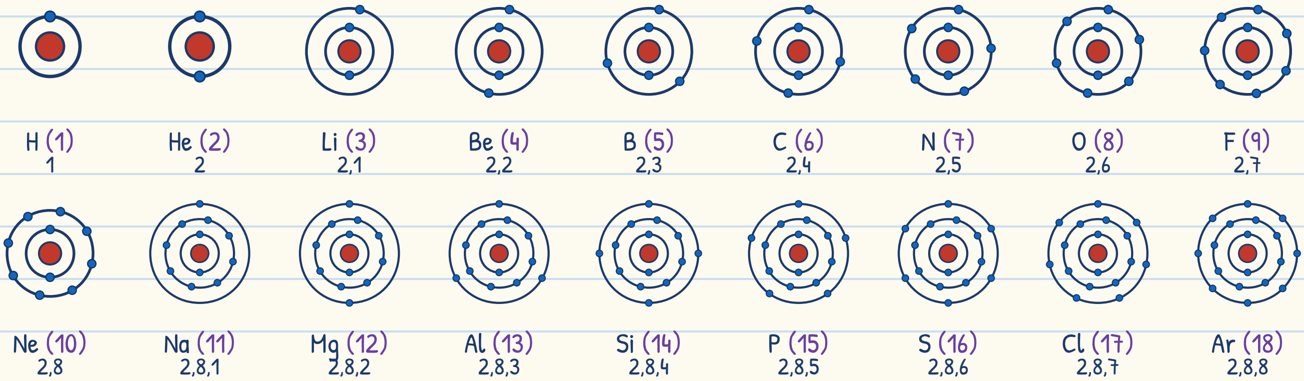



Fig. 8.11 — Schematic atomic structures of the first 18 elements (red centre = nucleus, blue dots = electrons; the number in brackets is Z)

Table 8.4 — The first eighteen elements (with the valency column added, as the book asks)

| Element | Symbol | Z | $p^+$ | $n^0$ | $e^-$ | K | L | M | N | Valency |
|---|---|---|---|---|---|---|---|---|---|---|
| Hydrogen | H | 1 | 1 | – | 1 | 1 | – | – | – | 1 |
| Helium | He | 2 | 2 | 2 | 2 | 2 | – | – | – | 0 |
| Lithium | Li | 3 | 3 | 4 | 3 | 2 | 1 | – | – | 1 |
| Beryllium | Be | 4 | 4 | 5 | 4 | 2 | 2 | – | – | 2 |
| Boron | B | 5 | 5 | 6 | 5 | 2 | 3 | – | – | 3 |
| Carbon | C | 6 | 6 | 6 | 6 | 2 | 4 | – | – | 4 |
| Nitrogen | N | 7 | 7 | 7 | 7 | 2 | 5 | – | – | 3 |
| Oxygen | O | 8 | 8 | 8 | 8 | 2 | 6 | – | – | 2 |
| Fluorine | F | 9 | 9 | 10 | 9 | 2 | 7 | – | – | 1 |
| Neon | Ne | 10 | 10 | 10 | 10 | 2 | 8 | – | – | 0 |
| Sodium | Na | 11 | 11 | 12 | 11 | 2 | 8 | 1 | – | 1 |
| Magnesium | Mg | 12 | 12 | 12 | 12 | 2 | 8 | 2 | – | 2 |
| Aluminium | Al | 13 | 13 | 14 | 13 | 2 | 8 | 3 | – | 3 |
| Silicon | Si | 14 | 14 | 14 | 14 | 2 | 8 | 4 | – | 4 |
| Phosphorus | P | 15 | 15 | 16 | 15 | 2 | 8 | 5 | – | 3 |
| Sulfur | S | 16 | 16 | 16 | 16 | 2 | 8 | 6 | – | 2 |
| Chlorine | Cl | 17 | 17 | 18 | 17 | 2 | 8 | 7 | – | 1 |
| Argon | Ar | 18 | 18 | 22 | 18 | 2 | 8 | 8 | – | 0 |

## Pause and Ponder Q14 – Q16

**14 Identify the number of electrons in the outermost shell of: (i) $^{12}_{6}C$ (ii) $^{19}_{9}F$ (iii) $^{28}_{14}Si$**

Ans.

- **(i) $^{12}_{6}C$** — $Z = 6 \Rightarrow 6$ electrons ⇒ configuration **2, 4** ⇒ **4** electrons in the outermost shell.
- **(ii) $^{19}_{9}F$** — $Z = 9 \Rightarrow 9$ electrons ⇒ configuration **2, 7** ⇒ **7** electrons in the outermost shell.
- **(iii) $^{28}_{14}Si$** — $Z = 14 \Rightarrow 14$ electrons ⇒ configuration **2, 8, 4** ⇒ **4** electrons in the outermost shell.

Remember: use the **lower** number (Z), not the mass number, to count electrons.

**15 Write the electronic configuration of the elements having atomic numbers 12, 16 and 18.**

Ans.

- **Z = 12 (Magnesium, Mg):** K = 2, L = 8, M = 2 ⇒ **2, 8, 2**
- **Z = 16 (Sulfur, S):** K = 2, L = 8, M = 6 ⇒ **2, 8, 6**
- **Z = 18 (Argon, Ar):** K = 2, L = 8, M = 8 ⇒ **2, 8, 8** — a complete octet, so argon is unreactive (a noble gas).

**16** **Solve this riddle: I am an atom with a mass number of 23 and 11 protons. I am a soft metal and react vigorously with water. Who am I and how many neutrons do I have?**

*Ans.* 11 protons ⇒ $Z = 11$ ⇒ I am **sodium (Na)**, written ${}^{23}_{11}Na$.

Neutrons $= A - Z = 23 - 11 =$ **12**

(Configuration 2, 8, 1 — one loose valence electron is exactly why sodium is so reactive.)

**Make your own riddle:** "I have 17 protons and 18 neutrons, I am a greenish-yellow gas and I disinfect your drinking water. Who am I?" → **Chlorine, ${}^{35}_{17}Cl$**.

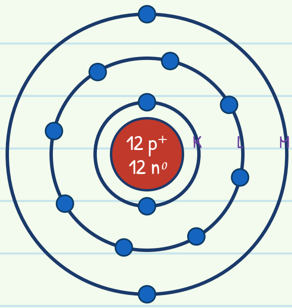
## Exercise Q8 & Q13 configuration practice

**8** **Magnesium is essential for many biological processes, including muscle contraction. For an atom of magnesium with mass number 24 and atomic number 12, determine (i) protons, (ii) neutrons, (iii) electrons, and illustrate the arrangement of electrons.**

*Ans.* **Given:** $A = 24$, $Z = 12$

- **(i) Protons** $= Z =$ **12**
- **(ii) Neutrons** $= A - Z = 24 - 12 =$ **12**
- **(iii) Electrons** = protons = **12**

**Arrangement:** K = 2, L = 8, M = 2 ⇒ **2, 8, 2**




Magnesium ${}^{24}_{12}Mg$ (2, 8, 2)

2 valence electrons ⇒ Mg loses them easily ⇒ valency 2 ⇒ forms $Mg^{2+}$ (as in $MgCl_2$).

13 **Complete Table 8.5.**

*Ans.* Use $Z = p^+ = e^-$ and $A = p^+ + n^0$. Filled-in values are shown in **green**.

| Atomic number | Mass number | Neutrons | Protons | Electrons | Name of element |
|---|---|---|---|---|---|
| 5 | **11** | 6 | **5** | **5** | **Boron** |
| **7** | 14 | **7** | **7** | 7 | Nitrogen |
| **12** | 24 | **12** | 12 | **12** | **Magnesium** |
| 15 | **31** | 16 | **15** | **15** | **Phosphorus** |
| **1** | 1 | 0 | **1** | **1** | **Hydrogen** |

**Working, row by row:**

- Row 1: $Z = 5 \Rightarrow p = e = 5$; $A = 5 + 6 = 11 \Rightarrow$ **boron**.
- Row 2: $e = 7 \Rightarrow Z = p = 7$; $n = 14 - 7 = 7 \Rightarrow$ nitrogen ✓.
- Row 3: $p = 12 \Rightarrow Z = e = 12$; $n = 24 - 12 = 12 \Rightarrow$ **magnesium**.
- Row 4: $Z = 15 \Rightarrow p = e = 15$; $A = 15 + 16 = 31 \Rightarrow$ **phosphorus**.
- Row 5: $A = 1$, $n = 0 \Rightarrow p = 1 \Rightarrow Z = e = 1 \Rightarrow$ **hydrogen** (the only atom with no neutron).

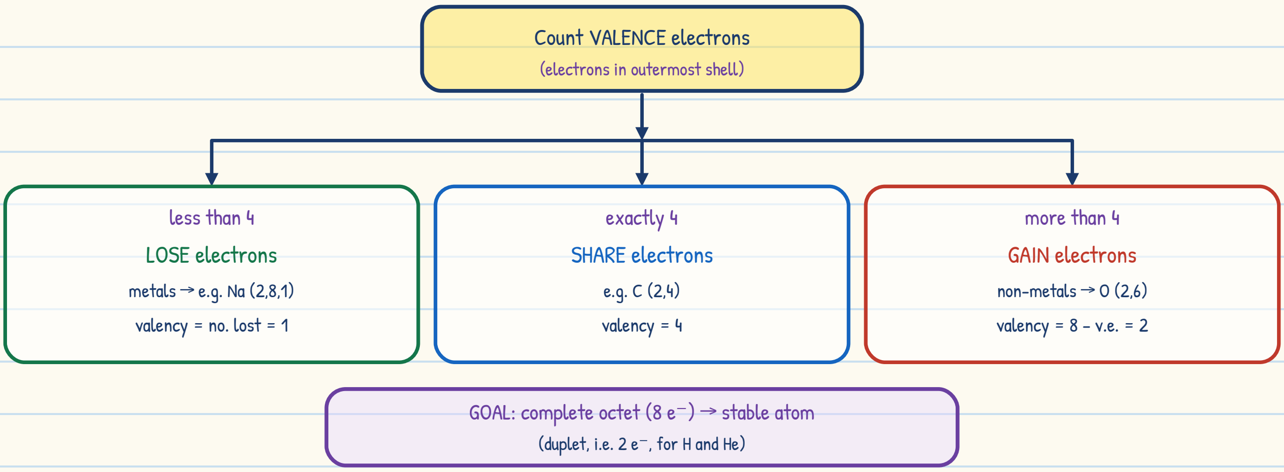
## 8.8 Combining Capacity of an Atom: Valency

DEF **Combining capacity** = the number of atoms of **hydrogen** or **chlorine** with which one atom of an element combines. (H and Cl are used as the yardstick because both have a combining capacity of **1**.)

| Compound | Element | Combines with | Combining capacity |
|---|---|---|---|
| $H_2O$ | Oxygen | 2 H atoms | **2** |
| $NH_3$ | Nitrogen | 3 H atoms | **3** |
| $MgCl_2$ | Magnesium | 2 Cl atoms | **2** |
| $CH_4$ | Carbon | 4 H atoms | **4** |

DEF **Valence shell** = the outermost shell of an atom that contains electrons.
**Valence electrons** = the electrons present in the valence shell.
**Octet** = a valence shell containing **8** electrons.
**Valency** = the number of electrons **gained, lost or shared** by an atom to complete its octet.

THE OCTET RULE Elements with a **complete octet** (8 valence electrons) — or **2** in the case of helium — are **largely unreactive and stable** (the noble gases). Atoms with incomplete valence shells are **reactive**: they lose, gain or share electrons to reach an octet.




Flow chart — how to find the valency of any element from its configuration

### *Worked examples of valency*

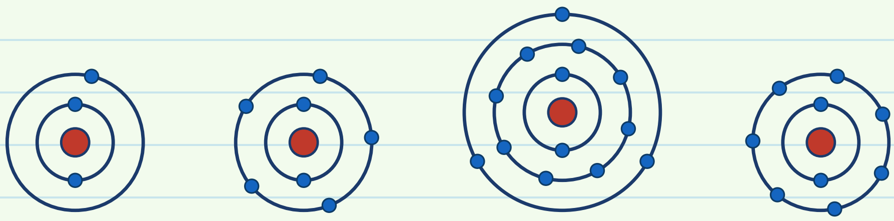
| Element | Configuration | Valence $e^-$ | What it does | Valency |
|---|---|---|---|---|
| Sodium (Na) | 2, 8, 1 | 1 | loses 1 $e^-$ → 2, 8 (octet) | **1** |
| Magnesium (Mg) | 2, 8, 2 | 2 | loses 2 $e^-$ | **2** |
| Carbon (C) | 2, 4 | 4 | shares 4 $e^-$ (cannot easily lose/gain 4) | **4** |
| Oxygen (O) | 2, 6 | 6 | gains 2 $e^-$ → 2, 8 | **2** |
| Chlorine (Cl) | 2, 8, 7 | 7 | gains 1 $e^-$ → 2, 8, 8 | **1** |
| Neon (Ne) | 2, 8 | 8 | nothing — already an octet | **0** |

***Can an atom that already has 8 valence electrons still lose or gain electrons? No — it has no reason to.*** *Its octet is already complete, so it is stable and does not normally react. Its valency is* ***0****. That is why neon, argon, etc., are called* ***noble*** *(inert) gases. Some compounds appear to break the usual valency rule — you will study these in higher classes.*

## Exercise Q9 read the diagrams

**9** **Find the following information for the elements shown in Fig. 8.17: (i) name, (ii) symbol, (iii) total electrons, (iv) valence electrons, (v) valency, (vi) protons, (vii) atomic number.**

*Ans.* First **count the dots** shell by shell, then everything else follows.



(a) 2, 1 (b) 2, 5 (c) 2, 8, 3 (d) 2, 7

| | (a) | (b) | (c) | (d) |
|---|---|---|---|---|
| (i) Name | **Lithium** | **Nitrogen** | **Aluminium** | **Fluorine** |
| (ii) Symbol | Li | N | Al | F |
| (iii) Total electrons | 3 | 7 | 13 | 9 |
| Configuration | 2, 1 | 2, 5 | 2, 8, 3 | 2, 7 |
| (iv) Valence electrons | 1 | 5 | 3 | 7 |
| (v) Valency | **1** | **3** | **3** | **1** |
| (vi) Protons | 3 | 7 | 13 | 9 |
| (vii) Atomic number (Z) | 3 | 7 | 13 | 9 |

**Why those valencies:** Li has 1 valence $e^-$ (< 4) → loses 1 → valency 1. N has 5 (> 4) → gains 3 → valency 3. Al has 3 (< 4) → loses 3 → valency 3. F has 7 (> 4) → gains 1 → valency 1.

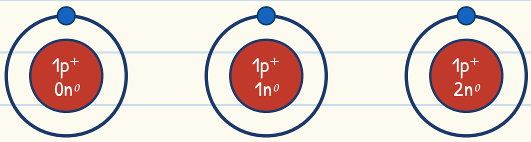
# 8.9 A Deeper Look into Atomic Structure

### » 8.9.1 Isotopes

Dalton said all atoms of an element are identical and equally heavy. Scientists later found this is **not true**: atoms of the same element can carry **different numbers of neutrons**.

DEF **Isotopes** = atoms of the **same element** having the **same atomic number (Z)** but **different mass numbers (A)** — i.e. the same number of protons but a different number of neutrons. Think of them as "twin atoms".

## Isotopes of hydrogen



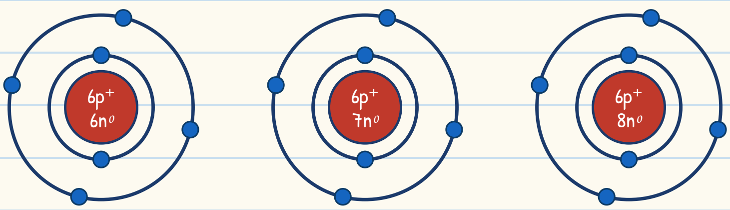

Protium $^{1}_{1}H$ Deuterium $^{2}_{1}H$ Tritium $^{3}_{1}H$

Fig. 8.12 — The three isotopes of hydrogen (all have 1 proton and 1 electron)

| Isotope | Symbol | $p^+$ | $n^0$ | $e^-$ | A | Natural abundance |
|---|---|---|---|---|---|---|
| Protium | $^{1}_{1}H$ | 1 | 0 | 1 | 1 | ≈ 99.98 % |
| Deuterium | $^{2}_{1}H$ | 1 | 1 | 1 | 2 | ≈ 0.015 % |
| Tritium | $^{3}_{1}H$ | 1 | 2 | 1 | 3 | traces only |

All three have **1 electron** — because all three have 1 proton and are neutral.

## Isotopes of carbon




Carbon-12 Carbon-13 Carbon-14

Fig. 8.13 — Isotopes of carbon; each has 6 protons and 6 electrons, only the neutrons differ

VERY IMPORTANT Isotopes have the **SAME chemical properties** — because chemical behaviour depends on the number of **valence electrons**, and all isotopes have the same number of electrons and the same electronic configuration.
They have **DIFFERENT physical properties** (density, melting point, boiling point, rate of diffusion) — because these depend on **mass**, and their masses differ.

## Uses of isotopes — Bridging Science and Society

| Isotope | Element | Use |
|---|---|---|
| $^{235}_{92}U$ | Uranium | **Fuel in nuclear reactors** to generate electricity in nuclear power plants (Fig. 8.14) |
| $^{60}_{27}Co$ | Cobalt (radioactive) | **Radiation therapy** for the treatment of cancer |
| $^{131}_{53}I$ | Iodine | Treatment of **goitre** and **thyroid cancer** |
| $^{14}_{6}C$ | Carbon | **Carbon dating** — finding the age of ancient fossils and artefacts in archaeology and geology |

*Ready to Go Beyond – the unit 'u'*

*Atoms are far too tiny to weigh in kilograms, just as a grain of wheat is measured in milligrams, not kilograms. So scientists use the* ***unified atomic mass unit (u)****. (The older name was amu, atomic mass unit.)*

## Exercise Q14 — a full case-study question

**14** **An element X has a mass number of 35 and contains 18 neutrons. (i) How many electrons and protons does X have? (ii) What is its atomic number? (iii) Identify X. (iv) Write its electronic configuration. (v) How many valence electrons does it have? (vi) What will be the mass number if two neutrons are added? (vii) What will be the relation of X with the new atom?**

*Ans.* **Given:** $A = 35$, $n^0 = 18 \Rightarrow p^+ = A - n^0 = 35 - 18 = 17$

- **(i)** Protons = **17**, electrons = **17** (neutral atom).
- **(ii)** Atomic number **Z = 17**.
- **(iii)** $Z = 17 \Rightarrow$ X is **chlorine (Cl)**, i.e. $^{35}_{17}Cl$.
- **(iv)** Configuration: K = 2, L = 8, M = 7 ⇒ **2, 8, 7**.
- **(v)** Valence electrons = **7** (so valency = 8 − 7 = 1; Cl gains 1 electron).
- **(vi)** Adding 2 neutrons: $n^0 = 20$, protons still 17 ⇒ new A = 17 + 20 = **37**, i.e. $^{37}_{17}Cl$.
- **(vii)** Same Z (17) but different A (35 and 37) ⇒ the two atoms are **isotopes** of each other. They are both chlorine and behave identically in chemical reactions.

## » A. Average Atomic Mass

*Chlorine occurs in nature as two isotopes — one of mass* ***35 u****, the other* ***37 u****, in the ratio* ***3 : 1****. So is the mass of a chlorine atom 35 u or 37 u?*

| Method | Calculation | Result |
|---|---|---|
| **Simple average** (ignores abundance — WRONG) | (35 + 37) ÷ 2 | **36 u** |
| **Weighted average** (uses % abundance — CORRECT) | (35 × 75/100) + (37 × 25/100) = 105/4 + 37/4 = 142/4 | **35.5 u** |

*Average atomic mass = **Σ** (mass of isotope × its % abundance) ÷ 100*

DON'T MISUNDERSTAND **No single chlorine atom weighs 35.5 u.** It means that in, say, **10,00,000** chlorine atoms there are about **7,50,000** atoms of $^{35}_{17}Cl$ and **2,50,000** atoms of $^{37}_{17}Cl$, and 35.5 u is their **weighted average**.

## Pause and Ponder Q17 – Q18

**17** **Two different atoms have 11 protons each, but one has 12 neutrons and the other 13 neutrons. How do their atomic numbers and mass numbers compare? Are they the same element or different elements?**

Ans. **Atomic numbers:** both have 11 protons ⇒ **Z = 11 for both — identical**.

**Mass numbers:** $A_1 = 11 + 12 =$ **23**; $A_2 = 11 + 13 =$ **24** — **different**.

**Same or different element?** The identity of an element is fixed by Z alone, so both are the **same element — sodium (Na)**. Since Z is the same but A differs, they are **isotopes**: $^{23}_{11}Na$ and $^{24}_{11}Na$. They will show identical chemical properties.

**18** **Bromine occurs as two isotopes, $^{79}_{35}Br$ (49.7 %) and $^{81}_{35}Br$ (50.3 %). Calculate the average atomic mass of bromine.**

Ans. Average atomic mass = (79 × 49.7/100) + (81 × 50.3/100)

= (3926.3 ÷ 100) + (4074.3 ÷ 100)

= 39.263 + 40.743

= **80.006 u ≈ 80 u**

Check: the two isotopes are almost equally abundant, so the answer should lie almost exactly midway between 79 and 81 — and 80 does. Always do this sanity check.

### » 8.9.2 Isobars

DEF **Isobars** = atoms of **different elements** having the **same mass number (A)** but **different atomic numbers (Z)**. They have the same total number of nucleons, but the protons/neutrons split differently.

| ISOTOPES | | |
|---|---|---|
| same Z · different A | | |
| same element, different neutrons | | |
| $^{1}_{1}H$ | $^{2}_{1}H$ | $^{3}_{1}H$ |
| protium | deuterium | tritium |
| 0 $n^0$ | 1 $n^0$ | 2 $n^0$ |
| chemical properties SAME (same $e^-$) | | |

| ISOBARS | | |
|---|---|---|
| same A · different Z | | |
| different elements, same nucleons | | |
| $^{40}_{18}Ar$ | $^{40}_{19}K$ | $^{40}_{20}Ca$ |
| 18 $p^+$ | 19 $p^+$ | 20 $p^+$ |
| 22 $n^0$ | 21 $n^0$ | 20 $n^0$ |
| chemical properties DIFFERENT | | |

Isotopes vs Isobars — the one comparison you must never mix up

### The classic isobar trio — all have A = 40

| Element | Symbol | Z ($p^+$) | $n^0$ | A |
|---|---|---|---|---|
| Argon | $^{40}_{18}Ar$ | 18 | 22 | **40** |
| Potassium | $^{40}_{19}K$ | 19 | 21 | **40** |
| Calcium | $^{40}_{20}Ca$ | 20 | 20 | **40** |

**Memory hook**

**Isotopes** → "o" for the same **atomic number** (same element, different weight). **Isobars** → "a" for the same **A** (mass number).

## Exercise Q3 isotopes vs isobars

3 **The composition of the nuclei of three atomic species X, Y and Z is given. X: 18 p, 19 n | Y: 17 p, 18 n | Z: 17 p, 20 n. Explain the relation between (i) Y and Z, (ii) Z and X.**

**Ans. Step 1 — work out Z and A for each:**

| Species | Protons = Z | Neutrons | A = p + n | Element |
|---|---|---|---|---|
| X | 18 | 19 | 37 | Argon |
| Y | 17 | 18 | 35 | Chlorine |
| Z | 17 | 20 | 37 | Chlorine |

**(i) Y and Z:** same atomic number (Z = 17) but different mass numbers (35 and 37) ⇒ they are **ISOTOPES**. Both are chlorine, so their chemical properties are identical; only their physical properties differ slightly.

**(ii) Z and X:** same mass number (A = 37) but different atomic numbers (17 and 18) ⇒ they are **ISOBARS**. They are different elements (chlorine and argon) with completely different chemical properties, but their atoms contain the same total number of nucleons.

# At a Glance — the whole chapter on one page

### Summary points (NCERT)

- ★ Atoms are the **building blocks of matter**.
- ★ **J. J. Thomson** — electrons are embedded in a positively charged sphere (plum pudding).
- ★ **Rutherford** — the atom is mostly empty space, with a dense, positively charged **nucleus** at the centre and electrons orbiting it.
- ★ **Niels Bohr** — electrons move in **fixed energy levels (shells)** around the nucleus.
- ★ Shells are named **K, L, M, N ...**
- ★ **James Chadwick** discovered the **neutron**.
- ★ The three subatomic particles are **electrons, protons and neutrons**.
- ★ An **octet** in the outermost shell (or 2 $e^-$ for helium) makes an atom **stable and unreactive**.
- ★ **Valency** = combining capacity = electrons gained, lost or shared to reach a stable configuration.
- ★ **Atomic number (Z)** = number of protons in the nucleus.
- ★ **Mass number (A)** = total number of nucleons (protons + neutrons).
- ★ **Isotopes** — same Z, different A. **Isobars** — same A, different Z.
- ★ **Average atomic mass** is calculated from the relative abundance of the isotopes in nature.

## » Formula & fact sheet (learn these cold)

| Formula / fact | Meaning & typical use |
|---|---|
| $Z = p^+ = e^-$ | Atomic number; true only for a **neutral** atom |
| $A = p^+ + n^0$ | Mass number = nucleons |
| $n^0 = A - Z$ | The most used line in every numerical |
| **Max $e^-$ in shell = $2n^2$** | K = 2, L = 8, M = 18, N = 32 |
| **Outermost shell $\leq$ 8 $e^-$** | ($\leq$ 2 if it is the K shell) |
| **Valency** | = valence $e^-$ if $\leq 4$ \| = 8 − valence $e^-$ if > 4 |
| **Avg. atomic mass** | Σ (isotope mass × % abundance) ÷ 100 |
| $d_{atom} \approx 10^{-10}$ m | Nucleus $\approx 10^{-15}$ m $\Rightarrow 10^5$ times smaller |
| α-particle = He nucleus | 2 $p^+$ + 2 $n^0$, charge +2, mass 4 u |
| $e^-$ charge = $-1.602 \times 10^{-19}$ C | Taken as −1 by convention |

## » Common exam traps

→ Counting electrons from the **mass number** instead of the atomic number. Always use Z.

- → Writing sodium as **2, 9** — the L shell stops at 8, so it must be **2, 8, 1**.
- → Saying the neutron was discovered by the gold foil experiment. It was **Chadwick, 1932**.
- → Saying isotopes have different chemical properties. They do **not** — only physical properties differ.
- → Confusing **"accelerating"** with "speeding up". In a circle, direction changes ⇒ it is accelerating even at constant speed.
- → Forgetting that **mass number is always a whole number**, while **average atomic mass can be a fraction** (e.g. Cl = 35.5 u).

### The Quest Continues ...

**Is it possible to completely understand everything that happens inside an atom?**

The story does not end with Bohr. We now know electrons do not travel on neat fixed tracks at all — they exist as **electron clouds**, and we can only predict where they are most likely to be, not exactly where they are. Instruments such as **Scanning Tunnelling Microscopes (STM)** and **Transmission Electron Microscopes (TEM)** now let us see individual atoms (Fig. 8.15). The journey inside the atom is far from over.

### Meet a Scientist – Homi Jehangir Bhabha

Indian physicist, known as the **father of the Indian nuclear programme**. He founded the **Tata Institute of Fundamental Research (TIFR)** and the **Bhabha Atomic Research Centre (BARC)**, for the peaceful use of atomic energy — generating electricity, supporting agriculture and advancing medical treatment.

### The Journey Beyond – things to try

- Make an **'Atomic Prediction Board'** game: give clues (Z, A, valency) and let friends name the element.
- Write a report on how atomic properties help us in **healthcare, energy, agriculture and technology**.
- Make a **role-play or story** — "Journey Inside the Atom" — with Dalton, Thomson, Rutherford, Bohr and Chadwick as characters.
- Create an **animation/simulation** of the atomic models using any digital tool.
- Draw a **bar graph** of the number of electrons in each energy level for any three elements.
- Explore the PhET simulations: phet.colorado.edu → "Rutherford Scattering" and "Isotopes and Atomic Mass"

— End of Chapter 8 · Journey Inside the Atom —

**This may not be the end ... the atom is still being discovered.**