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Class 9 — Science

Study Notes · NCERT Solutions · Extra Questions

Based on *Exploration — Textbook of Science for Grade 9*, NCERT First Edition 2026

NEP 2020 / NCF-SE 2023 aligned · All 13 Chapters

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How to use this book. Every chapter has three parts — **Part A: Study Notes** (concept-wise, point-wise, with tables and labelled diagrams), **Part B: NCERT Solutions** covering every question of *Revise, Reflect, Refine*, and **Part C: Extra Questions** for home-examination practice. Answer length is matched to the marks shown on each question, and answers are written point-wise so they can be revised and memorised quickly. Wherever a question asks for a well-labelled diagram, one has been drawn and labelled.

CBSE Class 9 Science (Code 086), Session 2026–27: Theory 80 marks + Internal Assessment 20 marks = 100. Unit I World of Living — 27 • Unit II Matter, Its Nature and Behaviour — 25 • Unit III Motion, Force, Work and Sound — 23 • Unit IV Earth as a System — 5.

Paper design (verified against the 2026–27 curriculum): Demonstrate Knowledge and Understanding 50% • Application of Knowledge and Concepts 30% • Formulate, Analyse, Evaluate and Create 20%. Question types include objective / very short answer, assertion–reason, short answer, long answer and source / case / passage-based integrated

questions, with roughly 33% internal choice. Duration 3 hours. A separate optional **Science at Advanced Level** paper is also offered from this session.

✓ How to use this document — and what it does not replace

This volume is written so that you do **not** need a second guide or market notes. For every chapter it gives you the study notes, all the NCERT *Revise, Reflect, Refine* solutions, and extra questions with marks shown. Use it as your main book. Two honest points, so that nothing surprises you later:

- **Keep your NCERT *Exploration* open beside this.** Every figure here is an **MLI-redrawn schematic** — correct in what it shows, but **not to scale** and not a copy of any textbook figure. Each one carries a note telling you so.
- **Where we have drawn no diagram, we say so openly.** For a few figures — the human ear, the longitudinal section of a flower, and Rutherford's gold-foil apparatus — a simplified redrawing would get the proportions wrong and teach you the wrong picture. In those places you will find an orange “**use the NCERT figure**” card instead, listing exactly which parts you must be able to name. That is deliberate: a misleading diagram is worse for you than no diagram.
- **If anything here disagrees with your printed NCERT book, the book wins.** Tell your faculty so that this volume can be corrected.
- Parts of this material were organised with AI assistance and then checked against the NCERT text and the CBSE curriculum. Every numerical has been worked through. An occasional slip may still remain.

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CHAPTER 1

Exploration: Entering the World of Secondary Science

Study Notes · Solved Examples, Activity & Pause-and-Ponder · Extra Questions

PART A — STUDY NOTES

What this chapter is for

Chapter 1 is the **orientation chapter** of *Exploration*. It adds no new factual content of its own; it explains **how science works** — how we simplify the world into models, how we use a precise shared language of symbols and units, what laws, theories and principles really mean, how predictions are made and tested, and why estimation matters. It carries no separate marks in the CBSE weightage table, but these ideas are used directly in the higher-order and case-study questions of every other chapter.

The symbols framing the page numbers of your textbook: the **magnifying glass** stands for careful observation — noticing patterns and what might otherwise be missed. The **compass** stands for direction — choosing the right model, asking the right questions, and knowing the limits of where an idea applies. Together they mean that exploration in science is not aimless wandering but making sense of the world with care and purpose.

1. Models — simplifying in order to understand

A **model** is a simplified way of looking at a real system, focusing only on what is most important for a given question.

- The natural world is complex and studying it in full detail is often impossible, so science uses models.
- Building a model always involves making **assumptions** and **deliberately ignoring certain details**. These choices are **not mistakes** — they are made on purpose to keep things simple enough while still allowing us to find the answer we are looking for.
- As models are made more complex, extra details are added back for greater accuracy.

Branch	How the real system is modelled	What is left out
Physics	A moving car represented as a single point	Its shape, size and internal parts
Chemistry	Atoms drawn as spheres joined by bonds	The true nature of the electron cloud
Biology	A cell drawn as a diagram highlighting key parts; the heart studied as a pump	Millions of molecules; the individual cells of the organ
Earth science	The Earth treated as a smooth sphere layered into distinct regions	Mountains, valleys and local irregularities
A falling object	Only the effect of gravity considered	Air resistance

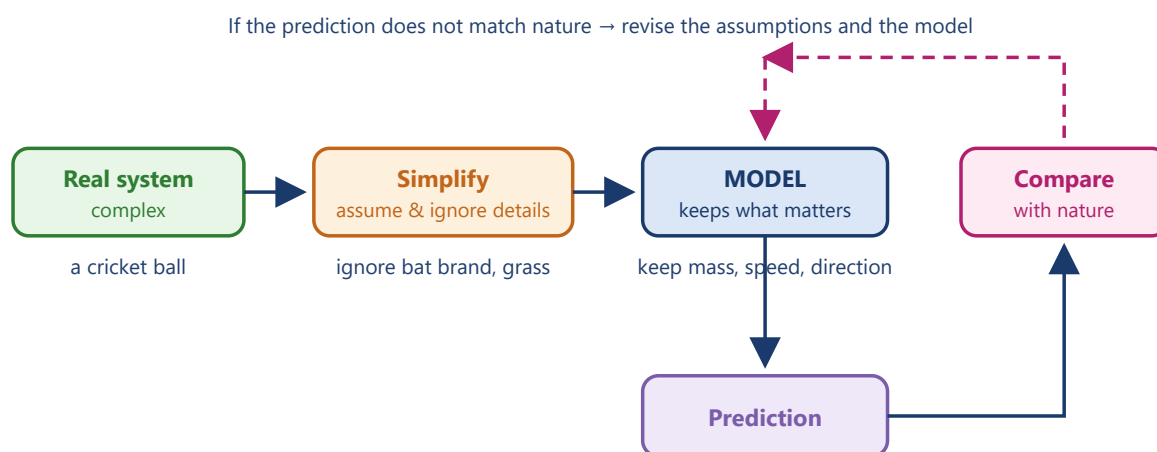


Fig. 1.A — How a scientific model is built, used and revised

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Meet a Scientist — Meghnad Saha, simplifying the stars. Studying the light from stars, he did not try to model every atom, every reaction or every movement inside a star. He treated the matter in the star simply as a **hot gas**, ignored many complex processes, and focused only on **temperature, pressure and how atoms**

formed ions. That deliberate simplification allowed him to explain how the colour of a star is connected to its temperature.

2. The language of science — terms, symbols and units

- Many everyday words — **force, work, cell, reaction** — carry **specific, narrow meanings** in science, because scientific ideas must be communicated clearly and unambiguously.
- Science uses a shared language of terms, symbols and units so that scientists across the world can describe observations, compare results and build ideas together.
- Quantities are given agreed symbols, each tied to a defined unit — mass **m**, velocity **v**, force **F**, electric current **I**.
- Symbols come from **history and international agreement**, not from convenience. The speed of light is written **c**, from the Latin *celeritas* meaning speed; it is today **defined** to be exactly $299,792,458 \text{ m s}^{-1}$.

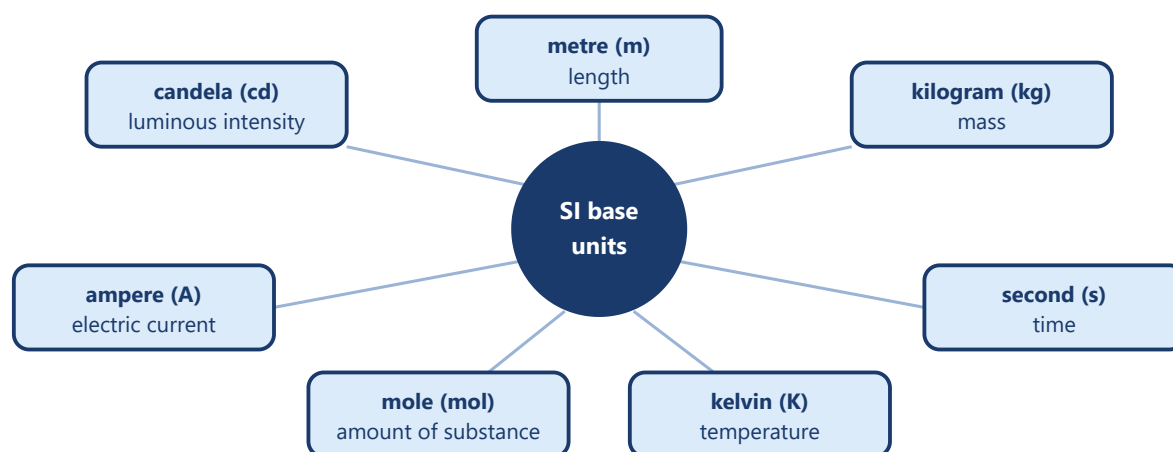


Fig. 1.B — The seven SI base units and the quantity each one measures

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Ready to Go Beyond — the aircraft that ran out of fuel. A passenger aircraft needed **22,300 kg** of fuel. The ground crew miscalculated the amount because they used the density of fuel in **pounds per litre** instead of **kilograms per litre**. The aircraft was left about **15,000 litres short**, ran out of fuel in mid-flight, and only luckily managed to glide to an emergency landing; the aircraft was damaged but there were no casualties. Using SI units everywhere removes conversions — and the errors that come with them.

Why a kilogram means the same everywhere. When we buy rice or vegetables we expect a kilogram to mean the same amount in every shop. Measurements are based on **agreed international standards**, not on local objects or opinions. Standard units let scientific results be compared, and ensure fairness in daily life and trade.

+ 3. Mathematics as a language for thinking

- Science turns to mathematics so that relationships between quantities can be **expressed clearly and tested carefully**.
- Mathematics in science is **not meant to be a hurdle**; it is a language that helps us think more clearly about the world.
- An equation is not just a calculation tool — it is a **compact statement about how things are related**. Describing motion through distance, time and velocity lets us answer where an object will be at a later moment; the same approach describes rates of reaction, patterns of population growth and changes of energy.
- **Using mathematics in science does not mean memorising equations**. The order of work is:

Understand the situation → identify the relevant quantities → use the relationship to reason carefully

- Focus first on the situation and the quantities involved, and equations stop feeling like obstacles and start acting as guides.

⚖️ 4. Laws, theories and principles — the exact meanings

Term	What it does	Example from your syllabus
Law	Describes a regular pattern observed in nature, in words or as a mathematical relationship — it tells us what happens	Newton's laws of motion explain the jerk felt when a bus stops suddenly
Theory	Goes a step further and explains why those patterns occur, based on evidence gathered over time	The atomic theory explains how molecules are formed
Principle	A broad idea that helps us make sense of a given situation	Conservation of energy, applied when climbing a staircase

The most important sentence in this chapter: in science, a **theory does not mean a guess** or an untested idea. It is an explanation based on careful testing and critical examination. Such ideas are always open to improvement and often change as new evidence becomes available — and that is exactly what makes science reliable.

💡 5. Prediction — and what happens when it fails

- When laws, theories and models are well established, they let us **anticipate what will happen** under new conditions — before an experiment is performed, and in many cases even when it cannot be performed.
- Examples: how far a kicked football will travel; how much carbon dioxide a reaction will produce, or how soft a baked bread will be; how breathing changes while running.
- These predictions are **not guesses** — they are reasoned expectations based on evidence and careful thinking.
- When predictions **match** observations, confidence in the underlying science grows.
- When they **do not match**, scientists re-examine their assumptions, models or measurements. Ideas are rejected only on **evidence**, never on opinion or belief.
- Even the most successful theories have limits and may fail when new conditions are explored or measurements become more precise. **No scientific theory is ever final and none is beyond question** — this openness to being corrected by nature itself is science's greatest strength.

Why weather forecasts sometimes go wrong. Weather depends on many changing factors — temperature, pressure, humidity and wind. Forecasts use measurements and models, but very tiny differences in conditions can grow over time and lead to something completely different. That is why forecasts are usually reliable for a few hours or days, but less certain further into the future.

Checking a "viral" claim — is eating food during an eclipse harmful? Disproof comes from asking simple scientific questions. An eclipse is only a play of shadows. What physical change actually occurs? Does the temperature change significantly? Does food go bad merely because it is left in a shadow? You will conclude that **no physical, chemical or biological mechanism** supports the claim.

6. Estimation — reasoning matters more than exact calculation

- A helpful strategy: first **understand the situation**, then **identify the quantities that matter**, and finally make a **rough estimate** to check whether an answer makes sense.
- Exact values are not always necessary, especially in the early stages of reasoning.
- An approximate estimate is often enough to tell whether a result is **reasonable or impossible**.
- Learning to estimate helps you build intuition, detect errors and develop confidence in your thinking.
- **Science values careful reasoning perhaps much more than accurate calculations.**
- *Ready to Go Beyond* — *how much rice would feed a family of four for a month?* Assume all their calorie needs come from rice; an average adult needs about **2000–2500 kcal a day**; find how many calories 100 g of uncooked rice provides and scale it up. The aim is not an exact number but a sanity check: 100 g for a month is clearly far too little, while a few tonnes is far too much.



7. Science has no real boundaries

- After Grade 10 science is divided into physics, chemistry, biology and earth science — but **the natural world has no such boundaries**. The divisions are made by us only to help organise knowledge; they are not independent of each other.
- Most real-world problems today — understanding climate change, developing medicines, designing sustainable technologies — require ideas from **several disciplines together**.
- Science also connects naturally with mathematics, technology, the arts and the social sciences.



One everyday object — four branches of science needed together

Fig. 1.C — Real problems cut across the branches of science

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Science as a human activity. Science is not just a collection of facts, equations or experiments. It is a human activity shaped by **curiosity, creativity, collaboration and careful questioning**. It grows as people ask questions, test ideas, share results and learn from mistakes, and it develops over time through the work of many individuals across different cultures and generations. Even if you do not study science beyond Grade 10, scientific thinking helps you understand the technology around you and evaluate information critically.

PART B — SOLVED EXAMPLES, ACTIVITY AND PAUSE-AND-PONDER

Chapter 1 has **no numbered "Revise, Reflect, Refine" exercise**. In its place the chapter carries three worked **Examples**, one **Activity** and three **Pause and Ponder** questions. All seven are solved below.

Example 1.1

3 Marks

A cricket shot. Think of a cricket ball being hit for a six. You want to make a simple model. What details would you include? What would you ignore?

SOLUTION

- **First fix the question:** "Will the ball cross the boundary without hitting the ground first?" A model can be built only once the question is clear.
- **Details to include** — those that decide the answer:
 - the **mass** of the ball;
 - the **speed** with which it has been hit;
 - the **direction** in which it has been hit.
- **Details that make no difference at all** and can be dropped outright: the brand of the bat, the colour of the ball, the amount of grass on the field.
- **Details with a smaller effect**, ignored in a simple model: air resistance, the spin of the ball, the stitching of the threads at the seam.
- As we build more complex models we **add these extra details back** for greater accuracy. Leaving them out at first is a deliberate choice, not an error.

Activity 1.1

3 Marks

Let us model. You ride a bicycle from school to home and want to model the time it takes. What details would you keep? What could you ignore? Why may ignoring some details actually be useful?

DETAILS TO KEEP

- The **distance** from school to home.
- Your **average cycling speed**.
- Large, predictable delays — a railway crossing, two or three traffic signals, a steep climb.

DETAILS THAT CAN BE IGNORED

- The colour and brand of the bicycle, and what you are wearing.
- Small moment-to-moment changes in pedalling speed.
- Air resistance, exact tyre pressure, small bumps in the road.
- Whether you stop briefly to wave to a friend.

WHY IGNORING DETAILS IS USEFUL

- The simple model **time** $\approx$ **distance** $\div$ **average speed** gives a usable answer in seconds.
- Including every detail would make the calculation impossibly complicated without improving the answer in any meaningful way.
- The estimate is good enough for the real purpose — knowing when to leave school in order to reach home on time.
- If the estimate turns out to be consistently wrong, you then **add back** the one detail that matters, such as the wait at the level crossing.

Example 1.2

3 Marks

Varsha tells Meghna, "It will rain this afternoon because the clouds look dark." Think of some questions Meghna could ask to make this prediction scientifically testable.

SOLUTION

- Good scientific questions look for **measurable evidence** and **past patterns**. Questions with simple yes/no answers are usually not very useful.
- Meghna could ask:
 - What was the condition of the sky the last time it rained?
 - What is the humidity today — was it above 80 per cent the last time it rained?
 - What is today's wind speed and direction?
 - Is the temperature dropping the way it did before the recent rains?
- Each question asks about **measurable data** and **past patterns**, which goes well beyond "the clouds look dark".
- This turns a casual remark into a prediction that can be checked against evidence — and, importantly, one that could be shown to be wrong.

Example 1.3

4 Marks

Estimate how many litres of air you breathe in one day. Start by estimating how many breaths you take per minute and the volume of one breath. The aim is a reasonable estimate, not an exact answer.

STEP 1 — NUMBER OF BREATHS IN A DAY

- At rest we take about **12–15 breaths per minute**.
- Minutes in a day = $60 \times 24 = 1440$.
- Breaths per day $\approx 18,000$ – $22,000$, i.e. roughly **20,000 breaths a day**.

STEP 2 — VOLUME OF ONE BREATH

- It takes about **4–5 breaths to fill a typical rubber party balloon**.
- An inflated balloon holds about **2 litres**.
- So one breath $\approx 2 \div 4 = 0.5$ litre.

STEP 3 — THE ESTIMATE

- Air breathed per day $\approx 20,000 \times 0.5 =$ **about 10,000 litres**.

STEP 4 — CROSS-CHECK BY A SECOND ROUTE

- A balloon takes about 20 s to blow up, so roughly **3 balloons per minute**.
- $3 \text{ balloons/min} \times 2 \text{ litres/balloon} \times 1440 \text{ min/day} = 8640 \text{ litres}$.
- 8640 L and 10,000 L agree closely enough for estimation purposes — which is exactly what we wanted.
- (Blowing balloons non-stop would of course exhaust us very quickly, unlike normal restful breathing.)

About 10,000 litres of air a day (order of magnitude 10^4 L)

Pause & Ponder 1

3 Marks

Think of a prediction you or your family made recently, for example the outcome of a cricket match. Was it based on evidence and reasoning, or mainly on guesswork? How can scientific thinking improve such predictions?

SAMPLE ANSWER

- **The prediction:** "Our team will win tomorrow's match."
- **Usual basis:** mainly guesswork — loyalty to the team, a feeling, or one recent good performance.
- **How scientific thinking improves it:**
 - Use **measurable evidence** — the win-loss record of both sides over the last ten matches.
 - Look for **past patterns** — performance at this particular ground and against this particular opponent.
 - Identify the **quantities that matter** — recent batting averages, bowling economy, injuries, the pitch report, the weather.
 - State the prediction so that it can be **checked and shown wrong**, then compare it with the actual result.
- **Conclusion:** the prediction becomes a **reasoned expectation based on evidence** rather than a hope. Like a weather forecast, it can still turn out wrong, because many factors keep changing — and that too is part of scientific honesty.

Pause & Ponder 2

2 Marks

Describe one situation where an approximate answer is good enough, and one where you would need a very exact value.

WHERE AN APPROXIMATE ANSWER IS ENOUGH

- Estimating how much rice to cook for guests, or roughly how long a bus journey will take.
- Checking whether a calculated answer is sensible — realising at once, for instance, that a walking speed of 200 m s^{-1} must be wrong.

WHERE AN EXACT VALUE IS ESSENTIAL

- Calculating the **fuel load of an aircraft** — the incident described in this chapter shows what a unit error can cost.
- Measuring the **dose of a medicine**, or the mass of a reactant in a chemical analysis.
- Machining an engine part, where a fraction of a millimetre decides whether it fits.

Pause & Ponder 3

4 Marks

Choose a real-life object or problem and make a sketch listing the ideas from physics, chemistry, biology, earth science or mathematics involved. Show how at least two branches connect.

SAMPLE ANSWER — THE PRESSURE COOKER

Branch	Ideas involved
Physics	Pressure, heat transfer, the rise of boiling point with pressure; the working of the weight and the safety valve
Chemistry	Aluminium or stainless steel and their behaviour with food; the chemical changes of cooking
Biology	Softening of starch and protein; destruction of harmful microbes; retention of nutrients
Earth science	Cooking takes longer at high altitudes because atmospheric pressure is lower
Mathematics	Relating pressure, temperature and cooking time; scaling quantities for more people

HOW TWO BRANCHES CONNECT

- **Physics and biology:** the raised pressure lifts the boiling point of water above 100°C , and it is that higher temperature which breaks down tough plant fibres and kills microbes faster. Neither branch alone explains why the cooker saves both time and fuel.
- This is exactly the chapter's point — the divisions of science are made by **us**, to organise knowledge. Nature does not work in separate compartments.

PART C — EXTRA QUESTIONS (SOLVED)

E1**1 Mark**

In science, a **theory** means

- (i) a guess that has not been tested
- (ii) an explanation based on careful testing and evidence
- (iii) a pattern observed in nature
- (iv) a rough estimate

(ii) an explanation based on careful testing and evidence

E2**1 Mark**

The symbol **c** for the speed of light comes from the Latin word

- (i) centum (ii) celeritas (iii) corpus (iv) calor

(ii) celeritas

E3**1 Mark**

The SI base unit of the amount of a substance is the

- (i) kilogram (ii) kelvin (iii) mole (iv) candela

(iii) mole

E4**1 Mark**

Ignoring air resistance while studying a falling object is

- (i) a mistake in the experiment
- (ii) a deliberate simplification made while building a model
- (iii) proof that air resistance does not exist
- (iv) a violation of scientific method

(ii) a deliberate simplification made while building a model

E5**1 Mark**

Assertion (A): No scientific theory is final or beyond question.

Reason (R): When predictions do not match observations, scientists re-examine their assumptions, models and measurements.

- (i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E6

2 Marks

Distinguish between a scientific **law** and a scientific **theory**, giving one example of each.

SOLUTION

- A **law** describes a regular pattern observed in nature, often as a mathematical relationship; it tells us **what** happens. Example — Newton's laws of motion, which describe the jerk felt when a bus stops suddenly.
- A **theory** goes further and explains **why** that pattern occurs, on the basis of evidence gathered over time. Example — the atomic theory, which explains how molecules are formed.

E7

2 Marks

Why does science insist on a shared set of terms, symbols and units?

SOLUTION

- So that scientists across the world can describe observations, compare results and build ideas together **without ambiguity** — everyday words such as force and work would otherwise mean different things to different people.
- Agreed international standards also prevent costly conversion errors, as in the aircraft that ran out of fuel, and ensure fairness in everyday trade.

E8

2 Marks

Why is it wrong to say that the failure of a scientific theory shows the weakness of science?

SOLUTION

- When a prediction does not match observation, scientists **re-examine their assumptions, models and measurements** and improve them — the theory is corrected by nature itself.
- Ideas are rejected only on **evidence**, never on opinion, belief or authority. This openness to correction is precisely what makes scientific knowledge reliable, so such failures are a strength.

E9

3 Marks

Estimate the number of heartbeats in one day, and explain why the answer is useful even though it is not exact.

SOLUTION

- A resting heart beats about **70–72 times per minute**; take it as 70.
- Minutes in a day = $60 \times 24 = 1440$.
- Beats per day $\approx 70 \times 1440 \approx$ **1,00,000 beats** (about 10^5).
- **Why it is useful:** it gives the right **order of magnitude**. It tells us at once that an answer of 5,000 or of one crore must contain a mistake, and it builds intuition about how hard the heart works — without needing an exact figure, which varies anyway with age, activity and health.

E10

3 Marks

A message forwarded on social media claims that a certain metal bracelet cures joint pain. Write any four questions a scientifically-minded student would ask before believing it.

SOLUTION

- **What is the proposed mechanism?** Is there any known physical, chemical or biological process by which a metal band could act on a joint?
- **Was there a comparison group?** Were people wearing an ordinary identical bracelet compared with those wearing the special one?
- **How many people were tested, and how was "cure" measured?** A few personal stories are not evidence, and pain must be measured in the same way for everyone.
- **Who made the claim, and has it been independently repeated?** A result that only the seller can reproduce is not reliable.
- **Would the pain have improved on its own?** Many joint pains come and go by themselves — which is exactly why a comparison group is essential.

E11

4 Marks

Case study: A student models how long a bucket takes to fill from a tap, using only the flow rate and the bucket's volume. She predicts 60 s, but the bucket fills in 78 s. (i) Name two details her model ignored. (ii) Should she discard the model? (iii) What should she do next? (iv) What does this show about how science works?

SOLUTION

- **(i) Details ignored:** the water pressure dropping when other taps in the building are open; the flow rate not staying constant; splashing and spillage; the bucket being wider at the top than assumed.
- **(ii) No.** The model is a deliberate simplification and it gave an answer of the right order — about a minute, not a second or an hour. A mismatch is **information, not failure**.
- **(iii) What she should do next:** re-examine her **assumptions, model and measurements** — measure the flow rate again at the actual time of use, check the bucket's true volume, then add back the one detail that matters most (the varying flow rate) and test the improved prediction.
- **(iv) What it shows:** models are built by ignoring details on purpose; predictions are checked against observation; and when they do not agree, the model is **revised on evidence** rather than abandoned on opinion. That cycle is science at work.

"Science is not just a collection of facts." Explain with reference to models, evidence, prediction and the human nature of science.

SOLUTION

- **Science is about how we know, not only what we know.** It studies how observations lead to measurements, how patterns are expressed in symbols and equations, how models are built to represent complex systems, and how ideas are tested, often revised and sometimes discarded.
- **Models:** nature cannot be studied in full detail, so we build simplified representations that keep what matters and deliberately ignore the rest — a car becomes a point, an atom a sphere, the Earth a layered sphere.
- **Evidence:** claims are accepted or rejected on evidence alone, never on opinion, belief or the authority of the person making them. A theory in science is an explanation built on careful testing, not a guess.
- **Prediction:** established laws, theories and models let us anticipate what will happen in new conditions. Matching predictions strengthen confidence; failing ones send scientists back to re-examine their assumptions — which is how knowledge advances.
- **A human activity:** science is shaped by curiosity, creativity, collaboration and careful questioning, and has grown through the work of many people across cultures and generations. Even its division into branches is our own doing, made to organise knowledge.
- **Conclusion:** facts are the *product* of science; questioning, modelling and testing are the *activity* of science — and that activity stays useful in any field, whether or not one studies science further.

CHAPTER 2

Cell: The Building Block of Life

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

This chapter belongs to **Unit I — World of Living (27 marks)**, shared with Chapters 3, 11 and 12. Cell and Tissues together usually account for about 12–14 marks of the 80-mark annual paper. Osmosis, organelle functions and cell division are the highest-return topics.

2.1 How to Study Cells?

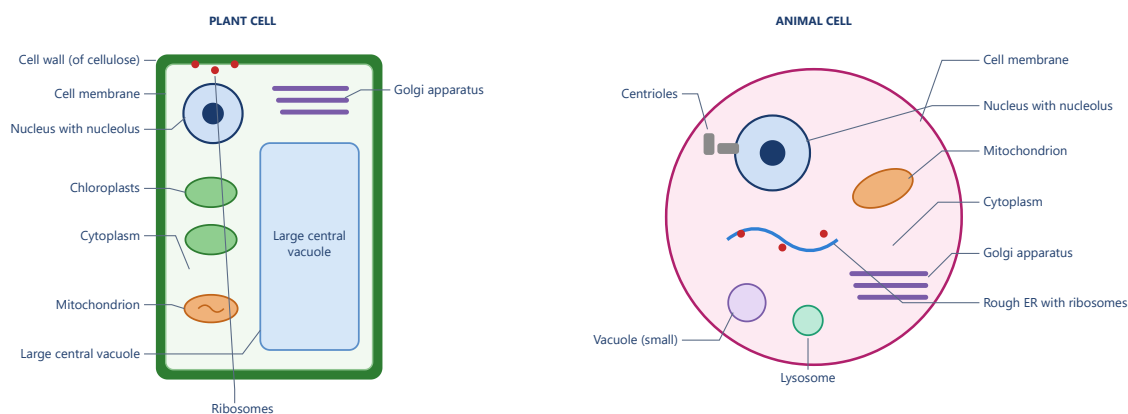
- **Robert Hooke (1665)** — examined a thin slice of cork under his own microscope, saw tiny box-like compartments and named them **cells** (from *cellula*, a small room). He saw only dead cell walls.
- **Anton van Leeuwenhoek** — first to see living, moving cells (bacteria, protozoa, sperm) in pond water.
- **Robert Brown (1831)** — discovered the **nucleus** in orchid leaf cells.
- **Purkinje (1839)** — coined the term **protoplasm** for the living contents of the cell.
- **Resolution** is the smallest distance between two points that can still be seen as separate. Light microscope ≈ 200 nm; electron microscope ≈ 0.2 nm — a thousand times better, which is why organelles were only discovered after the 1940s.
- **Staining** (safranin for plant cell walls, methylene blue for animal nuclei, iodine for starch) is needed because cell contents are transparent.

Size range: smallest bacterium ≈ 0.2 μm ; typical animal cell 10–30 μm ; human egg ≈ 100 μm (just visible); ostrich egg yolk is the largest single cell; nerve cells are the longest (up to 1 m).

2.2 Structure of a Cell — the three basic parts

Part	Structure	Function
Plasma (cell) membrane	Thin, flexible bilayer of lipids with proteins embedded	Separates cell from surroundings; selectively permeable — allows some substances in and out
Nucleus	Double nuclear membrane with pores; contains nucleolus and chromatin	Controls all cell activities; carries hereditary material (DNA)
Cytoplasm	Jelly-like fluid (cytosol) holding all organelles	Site of many chemical reactions; medium for organelles

Cell wall (plants, fungi, bacteria only): rigid outer layer, mainly **cellulose** in plants. It is **fully permeable** and gives shape, rigidity and protection from bursting. This is the key difference from the cell membrane, which is selectively permeable.



Only in the plant cell: cell wall · chloroplasts · one large central vacuole · fixed rectangular shape

Only in the animal cell: centrioles · lysosomes · many small vacuoles or none · irregular shape

In both: cell membrane · cytoplasm · nucleus · mitochondria · ribosomes · ER · Golgi apparatus

Fig. 2.A — Well-labelled comparison of a plant cell and an animal cell (schematic, not to scale)

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

💧 Diffusion and Osmosis — the most examined idea

Diffusion: net movement of particles of any substance from a region of higher concentration to lower concentration. No membrane needed. Example: exchange of O_2 and CO_2 across cell membranes; smell of incense spreading.

Osmosis: movement of **water** molecules from a region of **higher water concentration (dilute solution)** to a region of **lower water concentration (concentrated solution)** through a **selectively permeable membrane**.

Solution outside	Name	Net water movement	Effect on animal cell	Effect on plant cell
Dilute (more water)	Hypotonic	Into the cell	Swells, may burst (lysis)	Becomes turgid — cell wall prevents bursting
Same concentration	Isotonic	No net movement	No change	Flaccid
Concentrated (less water)	Hypertonic	Out of the cell	Shrinks (crenation)	Plasmolysis — protoplasm pulls away from the wall

Plasmolysis is the shrinking of the protoplasm away from the cell wall when a plant cell loses water to a hypertonic solution. Note: a dead cell cannot plasmolyse, because its membrane is no longer selectively permeable.

⚙ 2.3 The Cell Interior — organelles and their jobs

Organelle	Key structure	Function (learn these lines)
Endoplasmic reticulum — RER	Network of flattened sheets with ribosomes on the surface	Transport and processing of proteins
Endoplasmic reticulum — SER	Network of tubes, no ribosomes	Synthesis of lipids ; detoxification of drugs and poisons in liver cells
Golgi apparatus	Stack of membrane-bound cisternae	Modifies, packs and dispatches materials received from ER; forms lysosomes
Lysosome	Single-membrane sac of digestive enzymes	Digests worn-out organelles and foreign particles; "suicide bag" of the cell
Mitochondrion	Double membrane; inner folded into cristae; has own DNA and ribosomes	Aerobic respiration → releases energy as ATP ; "powerhouse"
Plastids (plants only)	Double membrane; own DNA	Chloroplast (green, chlorophyll) — photosynthesis; Chromoplast (red/orange/yellow) — colour of flowers and fruits; Leucoplast (colourless) — stores starch, oil, protein
Ribosome	No membrane; RNA + protein	Site of protein synthesis
Vacuole	Membrane (tonoplast) enclosing cell sap	Storage; provides turgidity and rigidity in plants
Nucleus	Double membrane with pores; nucleolus; chromatin	Controls cell activities; carries genes

Organelles with DNA: nucleus, mitochondrion, chloroplast. This is the reason mitochondria and plastids are called **semi-autonomous** organelles — they can make some of their own proteins.



Prokaryotic vs Eukaryotic cells

Feature	Prokaryotic (bacteria)	Eukaryotic (plants, animals, fungi, protists)
Nuclear membrane	Absent — nucleoid region only	Present — true nucleus
Membrane-bound organelles	Absent (no mitochondria, ER, Golgi, plastids)	Present
Ribosomes	Present, smaller (70S)	Present, larger (80S)
Chromosome	Single circular DNA, not in a nucleus	Several linear chromosomes inside nucleus
Size	1–10 μm	10–100 μm

2.4 Cell Division

Feature	Mitosis	Meiosis
Where	Somatic (body) cells	Reproductive cells (gamete-forming)
Divisions	One	Two (Meiosis I and II)
Daughter cells	2	4
Chromosome number	Same as parent ($2n \rightarrow 2n$)	Halved ($2n \rightarrow n$) — reduction division
Genetic result	Identical to parent	Variation (crossing over, independent assortment)
Purpose	Growth, repair, replacement, asexual reproduction	Formation of gametes; maintains chromosome number across generations

Stages of mitosis (order): Prophase → Metaphase → Anaphase → Telophase, followed by cytokinesis.
Memory hook: **P–M–A–T**.

Contact inhibition: normal animal cells stop dividing when they touch neighbouring cells. Loss of contact inhibition leads to uncontrolled division — a **tumour**.

2.5 Cell Theory

- Proposed by **Schleiden** (plants, 1838) and **Schwann** (animals, 1839); extended by **Rudolf Virchow** (1855).
- 1.** All living organisms are made of one or more cells.
- 2.** The cell is the basic structural and functional unit of life.
- 3.** All cells arise from pre-existing cells (*Omnis cellula e cellula* — Virchow).
- Exception often asked:** viruses are acellular, so they fall outside cell theory.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINED)

Q1

3 Marks

Differentiate between the following pairs of terms based on the clues given in parentheses: (i) Cell membrane and cell wall (permeability) (ii) RER and SER (structure) (iii) Chloroplasts and chromoplasts (pigments)

SOLUTION

- (i) Permeability:** The cell membrane is **selectively (partially) permeable** — it allows only certain molecules to pass and regulates what enters and leaves. The cell wall is **freely (fully) permeable** — water and dissolved substances pass through it without any regulation.
- (ii) Structure:** RER is made of flattened, sheet-like cisternae with **ribosomes attached** to its outer surface, giving it a rough look. SER is made of tubular membranes with **no ribosomes**, so its surface is smooth.
- (iii) Pigments:** Chloroplasts contain the **green pigment chlorophyll** (with carotenoids) and carry out photosynthesis. Chromoplasts contain **red, orange and yellow pigments (carotenoids)** but no chlorophyll, and give colour to flowers and fruits.

Q2

1 Mark

Cell X in pure water swells; Cell Y in concentrated salt solution shrinks. Which statement explains this correctly?

(iii) Water moved into Cell X and moved out of Cell Y through the cell membrane.

REASON

- The membrane is permeable to water but not freely to salt, so only water moves — this is osmosis.
- Pure water is hypotonic to the cell, so water enters Cell X and it swells.
- Salt solution is hypertonic, so water leaves Cell Y and it shrinks.

Q3

4 Marks

Identify the parts labelled (a) to (g) in Fig. 2.20 and match them with their functions.

SOLUTION — STRUCTURE MATCHED TO FUNCTION

Label	Part	Matching function
(a)	Cell wall	(v) Provides structural rigidity to the cell
(b)	Cell membrane	(iv) Separates the cell contents from surroundings
(c)	Nucleus	(i) Controlling all the activities of a cell
(d)	Chloroplast	(vii) Helps in manufacturing food
(e)	Mitochondrion	(ii) Site of cellular respiration
(f)	Golgi apparatus	(vi) Packs and stores materials received from ER
(g)	Vacuole	(iii) Storage organelle that also provides rigidity to the cell

Match by function, not by position on the page — the label order changes between editions, but "controls activities" is always the nucleus and "site of respiration" is always the mitochondrion.

Q4

1 Mark

Which option of the pairs of cell organelles is correctly placed under the given categories?

(i) Leucoplast (present in plant cells) and Cell wall (absent in animal cells)

WHY THE OTHERS ARE WRONG

- (ii) Mitochondria and ribosomes are present in **both** plant and animal cells.
- (iii) Cell wall is correct for plants, but the Golgi apparatus is **present** in animal cells.
- (iv) Lysosomes are typical of animal cells, and ER is present in animal cells too.

Q5

3 Marks

Renu says all parts of a plant, even roots, contain plastids. Rohit says plastids are absent in roots. Who is correct?

SOLUTION

- **Renu is correct.**
- Plastids are present in almost all plant cells, including root cells — but not always as green chloroplasts.
- Root cells contain **leucoplasts**, colourless plastids that store starch, oils and proteins (for example, the starch-filled leucoplasts of potato tubers).
- Rohit has confused "plastid" with "chloroplast". Photosynthesis is only one function of one type of plastid; storage and pigmentation are the others.
- Also, roots of some plants turn green and form chloroplasts when exposed to light, showing plastids can convert from one type to another.

Q6

5 Marks

Discuss how mitochondria and chloroplasts are structurally and functionally similar to, and different from, each other.

SIMILARITIES

- Both are **double-membrane-bound** organelles.
- Both possess their **own circular DNA and ribosomes**, so both are semi-autonomous and can synthesise some of their own proteins.
- Both can **divide independently** of the cell.
- Both have a large internal surface area (cristae in mitochondria, thylakoid membranes in chloroplasts) for membrane-bound reactions.
- Both are **energy-transforming** organelles.

DIFFERENCES

Point	Mitochondrion	Chloroplast
Occurrence	All eukaryotic cells	Green plant cells and algae only
Pigment	None	Chlorophyll
Internal structure	Inner membrane folded into cristae	Grana of stacked thylakoids in a stroma
Function	Releases energy by aerobic respiration; makes ATP	Traps light energy and stores it as glucose
Gas exchange	Uses O ₂ , releases CO ₂	Uses CO ₂ , releases O ₂

Q7

1 Mark

Which of the following pairs of cell organelles contains DNA?

(ii) Mitochondria, Nucleus

REASON

- Ribosomes, Golgi bodies and lysosomes contain no DNA.
- Chloroplasts also contain DNA, but option (i) pairs them with ribosomes, which do not — so (ii) is the only fully correct pair.

Q8

4 Marks

A researcher placed one carrot in plain water and another in concentrated salt solution for 24 hours. (i) What hypothesis is being tested? (ii) Suggest improvements. (iii) Why does one stay crunchy and the other become limp?

SOLUTION

- **(i) Hypothesis:** the direction of water movement into or out of plant cells depends on the concentration of the surrounding solution — i.e. carrot cells lose water in a hypertonic salt solution and gain water in plain water, by osmosis.
- **(ii) Improvements:**
 - Use carrots of the **same mass, length and freshness**, not merely similar size.
 - Measure and record **mass or length before and after** to get quantitative data instead of only "feel".
 - Keep both beakers at the same temperature and use the same volume of liquid.
 - State the salt concentration exactly, and repeat with several carrots to allow averaging.
 - Include a set kept in an isotonic solution as an additional control.
- **(iii) Explanation:** In plain water (hypotonic) water enters the carrot cells by osmosis; the vacuoles fill, the cells become **turgid** and press against their walls, making the carrot stiff and crunchy. In concentrated salt solution (hypertonic) water moves out of the cells; they become **flaccid and plasmolysed**, lose turgor pressure, and the carrot becomes rubbery and limp.

Q9

3 Marks

Indicate the presence or absence of the following structures in bacterial and animal cells.

SOLUTION

Structure	Bacterial cell	Animal cell
Chromosome	Present (single, circular, naked DNA in the nucleoid)	Present (several linear chromosomes inside the nucleus)
Nucleus	Absent (no nuclear membrane)	Present
Mitochondria	Absent	Present
Golgi complex	Absent	Present
Chromoplasts	Absent	Absent

The pattern to remember: a bacterium has genetic material but **no membrane-bound organelle at all**; an animal cell has every organelle except plastids and a cell wall.

Q10

3 Marks

Potato-cup experiment: Cup A empty, Cup B sugar, Cup C salt, Cup D sugar in a boiled potato, all standing in water. (i) Why does water gather in B and C? (ii) Why is Cup A necessary? (iii) Why does no water gather in A and D?

SOLUTION

- (i) The sugar or salt in the hollow makes the solution inside the cup **hypertonic** compared with the water in the beaker. Water therefore moves from the beaker, through the **living, selectively permeable** cells of the potato wall, into the hollow by osmosis, and collects there.
- (ii) Cup A is the **control**. It has living potato tissue but no concentration gradient. Since no water collects in it, we can be sure the water in B and C gathered because of the added solute and not simply because the potato was standing in water.
- (iii)
 - **Cup A:** there is no concentration difference across the potato wall, so there is no net osmosis.
 - **Cup D:** boiling has **killed the cells**; their membranes are no longer selectively permeable. Osmosis cannot occur across a dead membrane, so no water accumulates even though sugar is present.
- Cup D therefore proves a crucial point: **osmosis requires a living, selectively permeable membrane**, not merely a concentration difference.

Q11

1 Mark

Identify the pair that incorrectly matches the cell organelle with its function.

(iii) Lysosome — Digestion of foreign agents *is the pair listed as incorrect in the NCERT answer key*

EXPLANATION

- (i) Ribosome — protein synthesis: correct.
- (ii) SER — lipid synthesis: correct.
- (iii) The lysosome's principal role is intracellular digestion of the cell's own worn-out organelles and stored material; defence against foreign agents is carried out by specialised immune cells, so this match is treated as the incorrect one.

Q12

3 Marks

What outcome do you expect if all the mitochondria are removed from a eukaryotic cell?

SOLUTION

- Aerobic respiration would stop, so ATP production would fall drastically.
- All energy-requiring processes — active transport, protein synthesis, muscle contraction, cell division — would slow down and then stop.
- The cell could survive only briefly on the small amount of ATP from anaerobic glycolysis in the cytoplasm, which also causes a build-up of lactic acid or alcohol.
- Cells with high energy demand (muscle, nerve, liver) would die first.
- Eventually the cell would be unable to maintain its internal organisation and would die.

Q13

3 Marks

Which phenomenon inhibits the formation of tumours in the human body? Can plants also develop tumours? Explain.

SOLUTION

- The phenomenon is **contact inhibition** — normal animal cells stop dividing once they come into contact with neighbouring cells, which prevents unchecked multiplication.
- When cells lose contact inhibition they keep dividing and pile up, producing a **tumour**.
- **Yes, plants can also develop tumours**, called **galls** or crown galls.
- These are caused mainly by the bacterium *Agrobacterium tumefaciens*, and also by certain insects, fungi and viruses, which make plant cells divide abnormally.
- Plant tumours, however, do **not spread (metastasise)** through the body, because plant cells are held in place by rigid cell walls and plants have no circulatory system to carry loose cells.

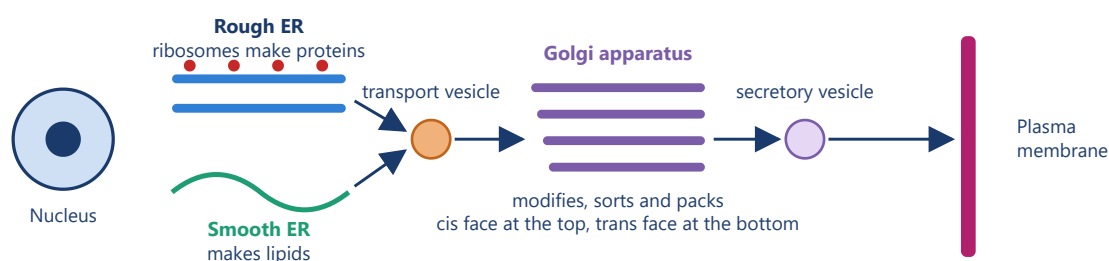
Which cell organelles help in the synthesis of the cell membrane? Write the path of these compounds from their site of synthesis to the cell membrane, and show it through a labelled diagram.

ORGANELLES INVOLVED

- **Ribosomes on the RER** — synthesise the membrane **proteins**.
- **SER** — synthesises the **lipids** (phospholipids and cholesterol).
- **Golgi apparatus** — modifies, sorts and packs both into vesicles.

PATH (IN ORDER)

- Proteins made on RER ribosomes enter the RER lumen; lipids are made in the SER.
- Both are packed into **transport vesicles** that bud off from the ER.
- These vesicles fuse with the **cis face** of the Golgi apparatus.
- Inside the Golgi the molecules are chemically modified (e.g. sugars added to form glycoproteins and glycolipids).
- Finished material leaves the **trans face** in secretory vesicles.
- The vesicle travels to the cell surface and **fuses with the plasma membrane** (exocytosis), adding its own membrane to it.



Order: Rough / Smooth ER → transport vesicle → Golgi → secretory vesicle → fuses with the plasma membrane

Fig. 2.B — Path of membrane components from the ER to the plasma membrane

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Q15

3 Marks

What would happen if gametes were formed by mitotic divisions?

SOLUTION

- Mitosis does not halve the chromosome number, so each gamete would carry the full **diploid (2n)** set instead of the haploid (n) set.
- At fertilisation the zygote would receive $2n + 2n = 4n$ chromosomes.
- The chromosome number would therefore **double in every generation**, and the species would lose its characteristic constant chromosome number.
- Such an imbalance would disturb gene dosage and normal development, and most such zygotes would not survive.
- There would also be **no genetic variation**, since mitosis produces identical cells — no crossing over and no independent assortment — reducing the species' ability to adapt and evolve.

Q16

4 Marks

Case study — Deepa preserves amla and lemons as pickles, murabbas and sharbat using salt, sugar or jaggery. (i) Which scientific concept has she applied? (ii) How do high concentrations of salt and sugar prevent spoilage? (iii) Suggest a healthy recipe of this kind. (iv) What scientific values are addressed?

SOLUTION

- **(i)** The concept applied is **osmosis** (osmotic preservation of food).
- **(ii)** Salt and sugar make the surrounding medium strongly **hypertonic**. Its concentration is much higher than the cell sap of bacterial and fungal cells, so water moves out of these microbial cells by osmosis. The cells become dehydrated and plasmolysed, and cannot grow or multiply. The low availability of free water also stops the enzyme activity that causes spoilage.
- **(iii) A healthy recipe:** amla murabba — steam fresh amla until just soft, prick the fruits, and keep them in a jaggery syrup with a little cardamom and black salt; store in a clean, dry glass jar. Using jaggery instead of refined sugar retains iron and minerals, and the amla retains most of its vitamin C. (A low-salt lemon pickle with turmeric and fenugreek works on the same principle.)
- **(iv) Scientific values addressed:** applying scientific knowledge to solve a real problem; reducing post-harvest waste; sustainability and resource conservation; food security; respect for traditional knowledge validated by science; and entrepreneurship that strengthens the local economy.

PART C — EXTRA QUESTIONS (SOLVED)

E1**1 Mark**

Which organelle is called the "suicide bag" of the cell?

(i) Golgi apparatus (ii) Lysosome (iii) Ribosome (iv) Vacuole

(ii) Lysosome

E2**1 Mark**

The term "cell" was coined by

(i) Leeuwenhoek (ii) Robert Brown (iii) Robert Hooke (iv) Purkinje

(iii) Robert Hooke

E3**1 Mark**

A plant cell placed in a strong sugar solution will

(i) burst (ii) become turgid (iii) undergo plasmolysis (iv) show no change

(iii) undergo plasmolysis

E4**1 Mark**

Assertion (A): An animal cell bursts when placed in distilled water but a plant cell does not.

Reason (R): The plant cell has a rigid cell wall that resists further expansion.

(i) Both A and R true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5**2 Marks**

Why is the plasma membrane called a selectively permeable membrane?

SOLUTION

- It permits the entry and exit of only some molecules, such as water, oxygen and carbon dioxide, freely.
- It restricts or regulates the movement of other molecules and ions, allowing them in only through specific channels or by active transport.
- This control keeps the internal composition of the cell different from its surroundings.

E6**2 Marks**

Dried raisins swell up when kept in water but shrink when kept in concentrated sugar solution. Explain.

SOLUTION

- In plain water the raisin's cell sap is hypertonic, so water enters the raisin cells by **endosmosis** and it swells.
- In concentrated sugar solution the outside is hypertonic, so water leaves the cells by **exosmosis** and the raisin shrinks further.

E7**2 Marks**

Name any two organelles that are present in a plant cell but absent in an animal cell, and state one function of each.

SOLUTION

- **Plastids** (e.g. chloroplast) — trap light energy and carry out photosynthesis.
- **Large central vacuole** — stores cell sap and provides turgidity and rigidity to the cell.
- (The cell wall is also plant-specific, though it is a covering rather than an organelle.)

E8**3 Marks**

Why is the mitochondrion called the powerhouse of the cell? Mention any two structural features that suit it to this role.

SOLUTION

- It is the site of **aerobic respiration**, where glucose is oxidised and the released energy is stored in **ATP**, the energy currency used for all cellular work.
- **Feature 1:** the inner membrane is deeply folded into **cristae**, greatly increasing the surface area available for the respiratory enzymes.
- **Feature 2:** it possesses its **own DNA and ribosomes**, so it can make some of its own proteins and multiply when the cell's energy demand rises.

E9

3 Marks

A student observes a cell under the microscope and notes: rigid outer boundary, a nucleus, and green bodies in the cytoplasm. Identify the type of cell and justify with three reasons.

SOLUTION

- It is a **plant cell** (specifically a green, photosynthetic plant cell such as a leaf cell).
- **Reason 1:** the rigid outer boundary is a **cell wall**, absent in animal cells.
- **Reason 2:** the green bodies are **chloroplasts**, found only in plant and algal cells.
- **Reason 3:** the presence of a true nucleus shows it is **eukaryotic**, ruling out a bacterial cell despite the cell wall.

E10

3 Marks

Differentiate between mitosis and meiosis on the basis of (i) number of daughter cells, (ii) chromosome number, and (iii) site of occurrence.

SOLUTION

Basis	Mitosis	Meiosis
Daughter cells	Two	Four
Chromosome number	Unchanged ($2n \rightarrow 2n$)	Halved ($2n \rightarrow n$)
Site	Somatic cells — growth, repair, replacement	Reproductive tissue — formation of gametes

E11

3 Marks

Why do we apply common salt to preserve raw mango pieces, and why does the mango release water afterwards?

SOLUTION

- Salt creates a strongly hypertonic layer around the mango pieces.
- Water moves out of the mango cells by **exosmosis** and collects as brine, which is why liquid appears in the jar.
- The same hypertonic condition dehydrates any bacterial or fungal spores present, so they cannot grow — the mango is preserved.

Draw a well-labelled diagram of a plant cell and list any five differences between a plant cell and an animal cell.

DIAGRAM

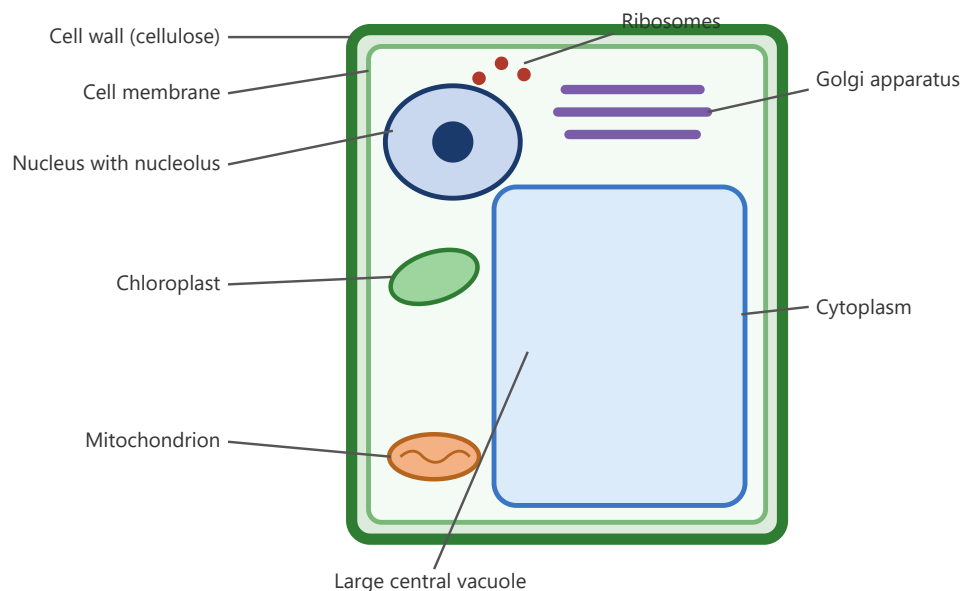


Fig. 2.C — A well-labelled plant cell (schematic, not to scale)

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

FIVE DIFFERENCES

Plant cell	Animal cell
Cell wall of cellulose present	Cell wall absent
Plastids present	Plastids absent
One large central vacuole	Many small vacuoles, or none
Centrioles usually absent	Centrioles present
Fixed, usually rectangular shape	Shape irregular and changeable

E13**4 Marks**

Case study: A student peels the inner lining of an onion, mounts it in water and observes it. She then replaces the water with a strong salt solution and observes again, and finally floods the slide with plain water. (i) What will she see at each stage? (ii) Name the two processes involved. (iii) What would happen if the peel had been boiled first?

SOLUTION

- **(i) In water:** cells appear full, with the protoplasm pressed against the cell wall — turgid. **In salt solution:** the protoplasm shrinks and pulls away from the cell wall, leaving a gap — the cells appear plasmolysed. **On re-adding water:** the protoplasm expands and again presses against the wall — the cells recover.
- **(ii) Plasmolysis** (water leaving by exosmosis) and **deplasmolysis** (water re-entering by endosmosis); both are examples of osmosis.
- **(iii)** A boiled peel has dead cells with non-functional membranes. No selective permeability remains, so neither plasmolysis nor recovery would be seen.

E14**5 Marks**

"The cell is the structural and functional unit of life." Justify this statement with suitable points.

SOLUTION

- **Structural unit:** every living body, from a bacterium to a blue whale, is built entirely of cells; there is no living structure below the level of a cell.
- **Functional unit:** all the processes that define life — nutrition, respiration, excretion, growth, response, reproduction — are carried out within cells.
- **Self-sufficiency:** a unicellular organism such as *Amoeba* performs every life function in a single cell, showing the cell alone can sustain life.
- **Division of labour:** in multicellular organisms, cells specialise (nerve, muscle, xylem) and group into tissues and organs, but the work is still done at cell level.
- **Continuity:** new cells arise only from pre-existing cells, and hereditary material is passed on from cell to cell, so the cell is also the unit of reproduction and inheritance.

CHAPTER 3

Tissues in Action

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit I — World of Living (27 marks)**. Plant tissues, animal tissues and the musculoskeletal system together are a reliable source of one long-answer and two short-answer questions. Diagrams of plant tissue types and joint types are frequently asked.

3.1 Why are plant and animal tissues different?

Tissue: a group of cells similar in structure and origin that work together to perform a specific function.

Plant tissues	Animal tissues
Plants are stationary — most support tissue is dead, which is cheap to maintain	Animals move — most tissues are living and consume much energy
Growth is restricted to certain regions (meristems)	Growth is uniform over the whole body
Differentiation is simple; cell structure varies little	Differentiation is complex and highly specialised
Tissue organisation supports vertical growth against gravity	Tissue organisation supports movement and rapid response

3.2 Plant tissues

A. Meristematic tissue — the dividing tissue

- **Features:** thin cellulose walls, dense cytoplasm, large prominent nucleus, few or no vacuoles, no intercellular spaces, cells actively dividing.
- **Apical meristem** — at root and shoot tips; increases **length** (primary growth).
- **Lateral meristem (cambium)** — in the sides of stem and root; increases **girth** (secondary growth); produces annual rings.
- **Intercalary meristem** — at the base of leaves or internodes (grasses, sugarcane); allows regrowth after grazing or mowing.

B. Permanent tissue — simple

Tissue	Structure	Function
Parenchyma	Living, thin-walled, loosely packed with large intercellular spaces	Storage, food manufacture; basic packing tissue
• Chlorenchyma	Parenchyma with chloroplasts	Photosynthesis
• Aerenchyma	Parenchyma with large air cavities (aquatic plants)	Buoyancy and gas exchange
Collenchyma	Living, irregularly thickened at corners with pectin and cellulose	Flexibility with strength — lets stems bend without breaking
Sclerenchyma	Dead , thick uniformly lignified walls, no lumen contents	Rigid mechanical strength — coconut husk, nut shells, jute fibre

C. Permanent tissue — complex (conducting)

Xylem	Phloem
Components: tracheids, vessels, xylem parenchyma, xylem fibres	Components: sieve tubes, companion cells, phloem parenchyma, phloem fibres
Mostly dead (only xylem parenchyma living)	Mostly living (only phloem fibres dead)
Carries water and minerals — upward only (unidirectional)	Carries food (sucrose) — in both directions (translocation)
Movement by transpiration pull — no energy spent by the plant	Movement requires energy (ATP)

Epidermis — outermost protective layer, usually one cell thick, coated with waxy **cuticle** in aerial parts; contains **stomata** guarded by bean-shaped guard cells for gas exchange and transpiration. Roots have root hairs instead of cuticle. **Cork (phellem)** — dead, suberin-coated cells of the bark; impermeable and protective.

3.3 Animal tissues — the four types

1. Epithelial tissue — covering and lining

- Cells tightly packed, almost no intercellular material, rest on a basement membrane, avascular (no blood vessels of their own).
- **Squamous** — flat, single-layered; lining of blood vessels and **alveoli**; permits rapid diffusion.
- **Stratified squamous** — many layers; skin; resists wear and tear.
- **Cuboidal** — kidney tubules, salivary ducts; absorption and secretion.
- **Columnar** — tall cells; intestine lining; absorption and secretion.
- **Ciliated columnar** — respiratory tract; cilia sweep mucus and dust outward.
- **Glandular** — epithelium folded inward to form glands that secrete enzymes, hormones or sweat.

2. Connective tissue — support and linkage

Type	Matrix	Function
Areolar	Soft, gel-like with fibres	Fills space between organs, supports internal organs, helps repair
Adipose	Fat-filled cells	Energy store; insulation; shock absorption
Cartilage	Solid but flexible; chondrocytes in lacunae	Smooth surfaces at joints; nose, ear pinna, trachea, larynx
Bone	Hard, rigid; calcium and phosphorus salts	Framework, protection of organs, muscle attachment
Blood	Fluid matrix = plasma	Transport of gases, nutrients, wastes, hormones; defence; clotting
Tendon	Dense, fibrous, strong, inelastic	Joins muscle to bone
Ligament	Dense, fibrous, strong and elastic	Joins bone to bone at a joint

3. Muscular tissue — movement

Feature	Striated (skeletal)	Smooth (unstriated)	Cardiac
Location	Attached to bones	Walls of gut, blood vessels, uterus	Heart wall only
Shape	Long, cylindrical, unbranched	Spindle-shaped	Cylindrical, branched
Nuclei	Many, at the edge (multinucleate)	One, central	Usually one, central
Striations	Present	Absent	Present (faint)
Control	Voluntary	Involuntary	Involuntary
Fatigue	Tires quickly	Tires slowly	Never tires

4. Nervous tissue — control and coordination

- Unit: the **neuron** — cell body (cyton), dendrites (receive impulses), a long axon (carries impulse away).
- Conducts electrical impulses rapidly over long distances; forms brain, spinal cord and nerves.

- Nerve cells are the longest cells in the body.

3.4–3.6 Musculoskeletal system and joints

- The **skeletal system** (206 bones in an adult human) gives shape, protects organs, stores minerals, produces blood cells in the marrow and provides attachment for muscles.
- **Axial skeleton:** skull, vertebral column, ribs, sternum. **Appendicular skeleton:** limbs and their girdles.
- Muscles work in **antagonistic pairs** — biceps contracts to flex the elbow while triceps relaxes, and the reverse to extend it. A muscle can only pull, never push.

Joint	Movement	Example
Ball and socket	All directions (rotation included)	Shoulder, hip
Hinge	In one plane only (back and forth)	Knee, elbow, ankle, fingers
Pivot	Rotation about an axis	Neck — skull on the atlas vertebra
Gliding	Small sliding movements	Wrist, ankle bones
Fixed (immovable)	None	Sutures of the skull, upper jaw

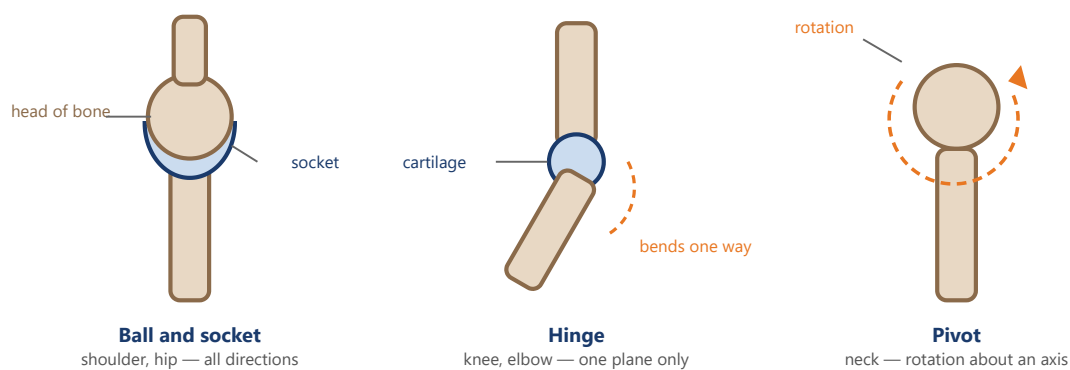


Fig. 3.A — The three main movable joints, labelled

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook *Exploration — Textbook of Science for Grade 9*.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1**1 Mark**

Meristematic tissues divide repeatedly. What property of their cells allows them to do this?

(iii) They have thin walls, dense cytoplasm and a large prominent nucleus.

REASON

- Thin walls allow the cell to expand and divide easily.
- Dense cytoplasm supplies the organelles and raw material needed for rapid division.
- A large nucleus controls the frequent replication of genetic material.

Q2**1 Mark**

If a plant is unable to transport food from leaves to roots, which tissue is malfunctioning?

(ii) Phloem

REASON

- Phloem conducts the food prepared in the leaves to every other part of the plant, including the roots.
- Xylem carries water and minerals upward only, so it cannot be the tissue at fault.

Note: the printed NCERT Answer Key lists option (iii) for this question. The option marked above is the one supported by the chapter content, so it has been retained. Students may follow their school's instruction if the key is quoted in class.

Q3**1 Mark**

Why are the epithelial tissues that line an animal's internal organs usually only one or a few cells thick?

(iii) To allow quick exchange of materials across them.

REASON

- Diffusion is fast only over very short distances.
- A thin lining, as in the alveoli and blood capillaries, minimises the diffusion path for gases, nutrients and wastes.

Note: the printed NCERT Answer Key lists option (ii) for this question. The option marked above is the one supported by the chapter content, so it has been retained. Students may follow their school's instruction if the key is quoted in class.

Q4

3 Marks

Straight-leg jump versus normal jump: how did your ankle, knee and hip positions differ?

SOLUTION

- **Straight-leg jump:** the ankle, knee and hip stay almost fully extended (straight). The joints hardly move, so the muscles cannot shorten much, and very little force and height are generated. The landing shock passes straight up the leg bones.
- **Normal jump:** before take-off the ankle, knee and hip all **flex** (bend), then extend powerfully together. On landing, all three flex again.
- **Why it matters:** bending allows the leg muscles to stretch first and then contract over a longer distance, producing far more force and a higher jump.
- On landing, bending increases the time over which the body is stopped, so the force on the joints is much smaller — this is the same principle as a high-jump landing mat.
- All three joints act as **hinge joints** working together with antagonistic muscle pairs.

Q5

1 Mark

Which type of joint is involved when you bend your knees and ankles?

(ii) Hinge

REASON

- Both the knee and ankle permit movement in essentially one plane, back and forth, which is the defining property of a hinge joint.
- A pivot joint allows rotation about an axis, as at the neck — that is not what happens at the knee or ankle.

Note: the printed NCERT Answer Key lists option (iii) for this question. The option marked above is the one supported by the chapter content, so it has been retained. Students may follow their school's instruction if the key is quoted in class.

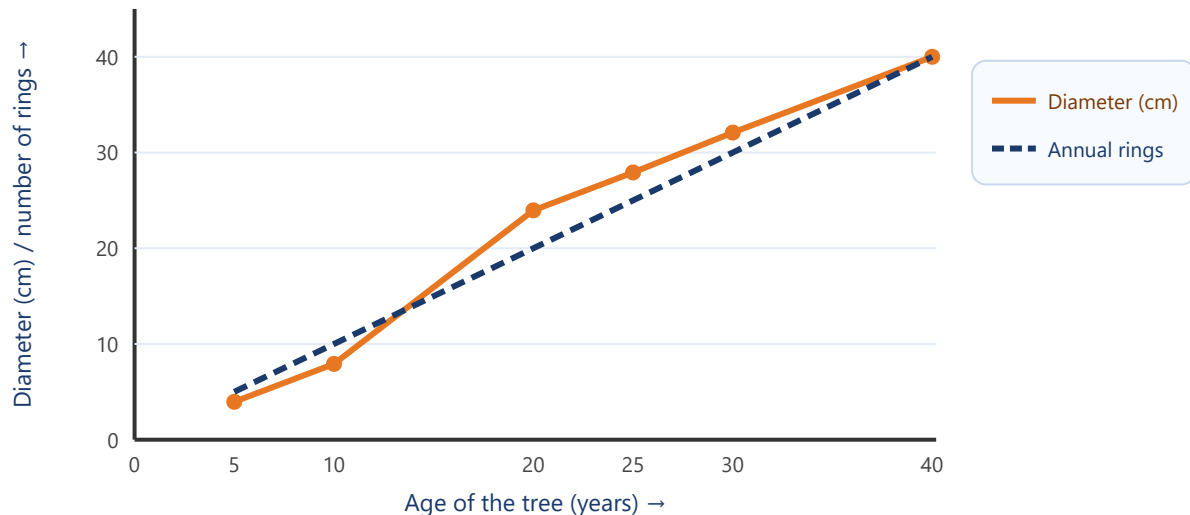
Assertion–Reason questions A, B, C and D.

SOLUTION

Part	Answer	Justification
A	(iii) A is true, but R is false	Lung epithelium is indeed suited to gas exchange, but because it is a single layer of flat squamous cells , not multiple layers of tall cells. The reason as written is wrong.
B	(i) Both true, R explains A	Cardiac muscle contracts without fatigue precisely because its cells are packed with mitochondria and richly supplied with blood, giving continuous aerobic ATP.
C	(iv) A is false, but R is true	Tendons join muscle to bone , not bone to bone (that is a ligament). The reason — that tendons are tough connective tissue transmitting force from muscle to bone — is correct.
D	(iii) A is true, but R is false	Hinge joints do move in one plane, but the bone ends are shaped to restrict movement to that plane, not to allow sliding in all directions.

Plot age of a teak tree against diameter and number of annual rings, then answer (i)–(iii).

THE GRAPH



Both rise together — roughly 1 cm of diameter and 1 ring are added each year

Fig. 3.B — Age of a teak tree plotted against stem diameter and number of annual rings

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

ANSWERS

- **(i) Interpretation:** the diameter increases steadily with age — from 4 cm at 5 years to 40 cm at 40 years. Growth in girth is slow in the first ten years, rises sharply between 10 and 20 years, and then continues at a fairly steady rate. Overall the relationship is close to **directly proportional**: roughly 1 cm of diameter is added each year.
- **(ii) Relation with annual rings:** the number of annual rings equals the age of the tree in years, and the diameter increases almost in step with the number of rings. So counting the annual rings gives the age, and the diameter is a rough measure of the same thing. Each ring represents one year's activity of the cambium.
- **(iii) Tissue responsible:** the **lateral meristem, i.e. the vascular cambium**. It lies as a thin ring between the xylem and the phloem in the stem and root, and by dividing it adds secondary xylem inward and secondary phloem outward, increasing the girth.

Q8

4 Marks

A tree is severely debarked by an elephant. (i) Which functions are hampered? (ii) Which tissue would be affected by further damage? (iii) Which function would be hampered then? (iv) What assumptions are you making?

SOLUTION

- (i) The bark contains the **phloem**, so the **translocation of food** from the leaves to the stem and roots is hampered. Protection against water loss, insects and pathogens provided by the cork is also lost.
- (ii) Further damage beneath the bark would injure the **vascular cambium** and then the **xylem**.
- (iii) Damage to the cambium stops **secondary growth**, so the tree can no longer increase its girth or repair its conducting tissue. Damage to the xylem stops the **upward transport of water and minerals** from roots to leaves, which halts photosynthesis and kills the tree.
- (iv) **Assumptions:**
 - The debarking goes all the way round the trunk (girdling); if only a strip were removed, the remaining phloem could still carry food and the tree might survive.
 - The tree is a dicot with a normal cambium ring, and the damage is deep enough to reach it.
 - No secondary infection sets in through the wound.

If the damage were only partial or shallow, the tree could recover by forming callus tissue over the wound, and the answer would change from "fatal" to "temporary setback".

Q9

3 Marks

A mango sapling's stem bends in monsoon winds without breaking. Which tissue is responsible? What if it were replaced by sclerenchyma?

SOLUTION

- The tissue responsible is **collenchyma**.
- Its living cells have walls unevenly thickened with pectin and cellulose at the corners, which gives **tensile strength together with flexibility**, so the young stem bends and springs back.
- **If replaced by sclerenchyma:** the walls would be uniformly thickened with **lignin** and the cells would be dead and rigid.
- The stem would become stiff and brittle; instead of bending in the wind it would **snap**.
- Rigid tissue would also hinder the elongation of the young growing stem, restricting further growth.

Q10**4 Marks**

Sugarcane cuttings: type B sprouted, type A did not. (i) Why? (ii) What difference existed? (iii) What was measured? (iv) What should be kept the same?

SOLUTION

- **(i)** Type B cuttings sprouted because they carried a **node with an axillary bud**. The bud contains **meristematic tissue**, which alone can divide and give rise to new shoots and roots. Type A cuttings were taken from the internode, which has only permanent tissue and cannot regenerate a new plant.
- **(ii)** The difference was the **presence of a node bearing a bud (meristem)** in type B and its absence in type A.
- **(iii)** The observation made was whether sprouting occurred — measured as the **number of cuttings that sprouted**, the number of days taken to sprout, and the length or number of new shoots after a fixed time.
- **(iv) Parameters to keep the same:** length and thickness of the cuttings, age and variety of the parent cane, same soil and pot, same quantity and frequency of watering, same light, temperature and humidity, same planting depth and orientation, and the same number of cuttings in each group.

Q11**3 Marks**

Rohan: "A tissue is a group of similar cells performing similar functions." Rajiv says this is true only for simple tissues. Explain.

SOLUTION

- **Rajiv is right.** Rohan's definition describes a **simple tissue** only.
- **Simple tissue** is made of one type of cell — e.g. parenchyma, collenchyma, sclerenchyma; all its cells look alike and do the same job.
- **Complex tissue** is made of **more than one type of cell** that together perform a common function.
- Example — **xylem** contains tracheids, vessels, xylem parenchyma and xylem fibres; the vessels conduct water, the fibres give support and the parenchyma stores food, yet all cooperate in the single function of water transport.
- Similarly **phloem** contains sieve tubes, companion cells, phloem parenchyma and fibres, cooperating in food transport; blood in animals is likewise a complex tissue.
- A better general definition is therefore: a tissue is a group of cells of **common origin** working together for a **common function**, whether or not the cells are alike.

Q12

3 Marks

Coconut husk fibres are tough and fibrous. Which tissue provides this strength, and why could living parenchyma not do the same?

SOLUTION

- The tissue is **sclerenchyma** (specifically sclerenchymatous fibres).
- Its cells are long and narrow, **dead at maturity**, with thick walls uniformly thickened by **lignin**, and no lumen contents — making them hard, tough and resistant to decay and tearing.
- **Parenchyma could not serve this purpose** because its cells are living, thin-walled, loosely packed with large intercellular spaces and full of water. They are soft and easily crushed, cannot bear tension, and would rot quickly once woven into a mat.

Q13

3 Marks

Vibha claims meristematic cells are located only at root and shoot apices. Comment, and suggest a question Neha could ask.

SOLUTION

- The statement is **incorrect**. Apical meristem is only one of three kinds.
- **Lateral meristem (cambium)** lies along the sides of stems and roots and increases girth.
- **Intercalary meristem** lies at the base of internodes or leaves, as in grasses and sugarcane.
- **Questions Neha could ask:** "If meristems were only at the tips, how does a tree trunk become thicker every year?" and "How does mown grass grow back from the base even after the tips have been cut off?"
- Both questions force Vibha to account for growth occurring away from the apices, and so lead her to lateral and intercalary meristems.

Q14

3 Marks

A plant cell and an animal cell are the same size. (i) Which will have a larger vacuole and why? (ii) What assumptions are you making?

SOLUTION

- (i) The **plant cell** will have the larger vacuole. A mature plant cell usually has a single large central vacuole occupying up to 80–90% of the cell volume. It stores cell sap, water, salts and pigments, and its **turgor pressure** pushes the protoplasm against the cell wall, giving the cell rigidity and support. Animal cells have only small, temporary vacuoles because they get their support from the cytoskeleton and the skeleton, not from turgor.
- (ii) **Assumptions:**
 - The plant cell is **mature** — a young meristematic plant cell has only tiny vacuoles, and then the answer would change.
 - The plant cell is well-watered and turgid, not plasmolysed.
 - The animal cell is a typical one, not a specialised storage or secretory cell.

Q15

3 Marks

A textbook states, "Each plant tissue performs only one specific function." What questions would you ask to examine this, and which tissues would you use?

SOLUTION

- **Questions to ask:**
 - Does any single tissue carry out more than one function at the same time?
 - Does the same tissue perform different functions in different organs of the plant?
 - Can a tissue change its function when the plant's needs change?
- **Tissues to examine:**
 - **Parenchyma** — stores food in the potato tuber, photosynthesises as chlorenchyma in leaves, gives buoyancy as aerenchyma in aquatic plants, and packs and supports elsewhere. One tissue, four functions.
 - **Xylem** — conducts water *and* provides mechanical support through its fibres.
 - **Epidermis** — protects, restricts water loss, and through stomata also carries out gas exchange.
- **Conclusion:** the statement is **too restrictive**. A tissue has one *principal* function, but many tissues perform several functions, so the claim does not survive examination.

PART C — EXTRA QUESTIONS (SOLVED)

E1**1 Mark**

Which tissue joins bone to bone?

(i) Tendon (ii) Ligament (iii) Cartilage (iv) Areolar tissue

(ii) Ligament

E2**1 Mark**

The only muscle that is branched and involuntary is

(i) skeletal (ii) smooth (iii) cardiac (iv) striated

(iii) cardiac

E3**1 Mark**

The fluid connective tissue in the human body is

(i) areolar tissue (ii) adipose tissue (iii) blood (iv) cartilage

(iii) blood

E4**1 Mark**

Assertion (A): Grass regrows quickly after mowing.

Reason (R): Grass possesses intercalary meristem at the base of its internodes.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5**2 Marks**

Why is the epidermis of desert plants thicker than that of plants in moist places?

SOLUTION

- A thicker epidermis carries a thicker waxy **cuticle**, which is impermeable to water.
- This greatly reduces water loss by transpiration in hot, dry conditions, and also protects against intense light and mechanical injury.

E6**2 Marks**

Give two reasons why most plant support tissue can afford to be dead, while animal support tissue must be living.

SOLUTION

- Plants are stationary and mainly need static mechanical strength, which a dead, lignified wall provides at almost no running energy cost.
- Animals move, grow uniformly and repair injuries continuously, so their supporting tissues (bone, cartilage) must contain living cells that respond, remodel and heal — which requires a blood supply and energy.

E7**2 Marks**

Name the tissue that (a) lines the windpipe and sweeps out dust, and (b) forms the pinna of the ear.

SOLUTION

- **(a)** Ciliated columnar epithelium.
- **(b)** Cartilage (a connective tissue).

E8**3 Marks**

Differentiate between xylem and phloem on the basis of (i) nature of cells, (ii) material conducted, (iii) direction of conduction.

SOLUTION

Basis	Xylem	Phloem
Nature of cells	Mostly dead; only xylem parenchyma living	Mostly living; only phloem fibres dead
Material conducted	Water and dissolved minerals	Prepared food, mainly sucrose
Direction	Unidirectional — roots to leaves	Bidirectional — from leaves to all parts, and from storage organs back

E9**3 Marks**

Athletes are advised to warm up before a race. Explain in terms of muscle tissue.

SOLUTION

- Warming up raises the temperature of skeletal muscle, increasing the rate of enzyme-controlled reactions and hence the speed of contraction.
- It increases blood flow to the muscles, supplying more oxygen and glucose and delaying the onset of anaerobic respiration and fatigue.
- It makes tendons and ligaments more extensible, reducing the risk of tears and sprains at the joints.

E10**3 Marks**

Why can a muscle only pull and never push? How does the body solve this problem?

SOLUTION

- A muscle produces force only when its fibres **shorten**; on relaxing it simply returns to its original length and exerts no force.
- Therefore one muscle alone can move a bone in one direction only.
- The body solves this with **antagonistic pairs** — e.g. the biceps contracts to bend the elbow while the triceps relaxes, and the triceps contracts to straighten it while the biceps relaxes.

E11**4 Marks**

Case study: A gardener removes a complete ring of bark from a branch of a mango tree (girdling). After some weeks a swelling appears just above the ring, the leaves above stay green for a while, and finally the branch dies. Explain each observation.

SOLUTION

- **Swelling above the ring:** the phloem has been cut, so food travelling downward from the leaves accumulates just above the cut and stimulates growth there.
- **Leaves stay green for a while:** the xylem lies deeper than the bark and is still intact, so water and minerals continue to reach the leaves and photosynthesis continues for some time.
- **Branch finally dies:** the tissues below the ring receive no food; the roots of that branch starve, the cambium there dies, and water transport eventually fails, killing the branch.
- **Conclusion:** the experiment demonstrates that food is carried by the phloem in the bark, while water is carried by the xylem deeper inside.

Draw a well-labelled diagram of a neuron and state the function of each labelled part.

DIAGRAM

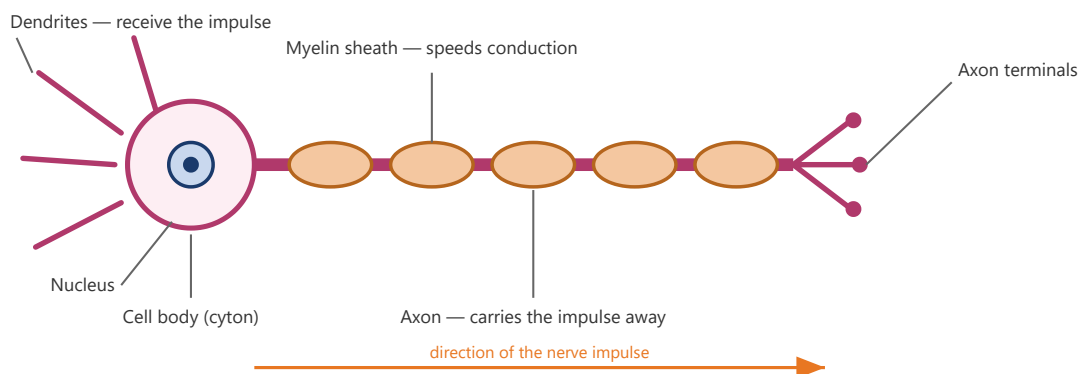


Fig. 3.C — A well-labelled neuron

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

FUNCTIONS

- **Dendrites** — receive impulses from other neurons or receptors and carry them towards the cell body.
- **Cell body (cyton)** — contains the nucleus and cytoplasm; maintains the cell and processes the incoming signal.
- **Nucleus** — controls the activities of the neuron.
- **Axon** — a single long fibre that carries the impulse away from the cell body.
- **Myelin sheath** — insulating fatty covering that speeds up impulse conduction.
- **Axon terminals** — pass the impulse on to the next neuron, muscle or gland across a synapse.

CHAPTER 4

Describing Motion Around Us

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit III — Motion, Force, Work and Sound (23 marks)**, shared with Chapters 6, 7 and 10. Motion alone usually carries 6–8 marks, and almost all of it is numerical or graph-based. Master the three kinematic equations and the area-under-the-graph method and this chapter is fully secured.

4.1 Basic quantities

Quantity	Definition	Type	SI unit
Distance	Total length of the actual path covered	Scalar (magnitude only)	m
Displacement	Shortest straight-line distance from initial to final position, with direction	Vector	m
Speed	Distance ÷ time	Scalar	m s^{-1}
Velocity	Displacement ÷ time	Vector	m s^{-1}
Acceleration	Change in velocity ÷ time	Vector	m s^{-2}

Key facts that earn marks:

- Distance is always positive; displacement can be positive, negative or **zero**.
- Displacement $\leq$ distance, always. They are equal only for motion in a straight line without reversal.
- If a body returns to its starting point, displacement = 0, so average velocity = 0, but average speed is not zero.
- Average speed = total distance ÷ total time. Average velocity = total displacement ÷ total time. These are not the same thing.

$$1 \text{ km h}^{-1} = 5/18 \text{ m s}^{-1} \quad \bullet \quad 1 \text{ m s}^{-1} = 18/5 \text{ km h}^{-1}$$

Rest and motion are relative. An object is at rest or in motion only with respect to a chosen **reference point (origin)**. A passenger sitting in a moving bus is at rest with respect to the bus but in motion with respect to the road.



4.2 Graphs of motion

Graph	Slope gives	Area under it gives
Position–time (x–t)	Velocity	No physical meaning
Velocity–time (v–t)	Acceleration	Displacement

- Straight horizontal line on x–t → object at rest.
- Straight sloping line on x–t → uniform velocity.
- Curved x–t → accelerated motion.
- Horizontal line on v–t → uniform velocity, zero acceleration.
- Sloping line on v–t → uniform acceleration; downward slope → retardation.
- Two x–t lines are **parallel** → the two objects have **equal velocity** at that moment. If they only cross, they have equal position, not equal velocity.

4.3 The kinematic equations (uniform acceleration only)

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

$$s = vt - \frac{1}{2}at^2 \quad \bullet \quad s = \frac{1}{2}(u + v)t$$

Sign convention: choose the direction of initial motion as positive. Then a retarding (braking) acceleration is negative, and a velocity in the opposite direction is negative. Always write down u, v, a, t, s before substituting — most lost marks come from mixed units, not from wrong physics.

Derivation of $s = \frac{1}{2}(u + v)t$ from the graph: the v–t graph of uniformly accelerated motion is a straight line, so the area under it is a **trapezium** with parallel sides u and v and height t. Area = $\frac{1}{2}(\text{sum of parallel sides}) \times \text{height} = \frac{1}{2}(u + v)t = \text{displacement}$.

4.4 Motion in a plane and uniform circular motion

- Motion in a plane needs two coordinates; velocity and acceleration must be handled as vectors.
- In **uniform circular motion** the speed is constant but the **direction of velocity changes continuously**. Since velocity changes, the motion is **accelerated**.
- Speed in a circle: $v = 2\pi r / T$, where T is the time for one revolution.
- After one complete revolution, distance = $2\pi r$ but displacement = 0. After half a revolution, displacement = $2r$ (the diameter).
- Examples: a stone whirled on a string, the tip of a clock hand, a satellite orbiting the Earth.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

2 Marks

Father goes 250 m to a shop, returns home for a bag, goes to the shop again, and comes back home. Find total distance and displacement.

SOLUTION

- Home → shop = 250 m
- Shop → home = 250 m
- Home → shop = 250 m
- Shop → home = 250 m
- **Total distance** = $250 \times 4 = 1000 \text{ m}$
- He finishes where he started, so initial and final positions coincide.

Distance = 1000 m; Displacement = 0 m

Q2

2 Marks

A student runs from the ground floor to the fourth floor, then down to the second floor. Height of each floor = 3 m. Find (i) total vertical distance, (ii) displacement.

SOLUTION

- Ground → 4th floor = $4 \times 3 = 12 \text{ m}$ upward
- 4th floor → 2nd floor = $2 \times 3 = 6 \text{ m}$ downward
- **(i) Total vertical distance** = $12 + 6 = 18 \text{ m}$
- **(ii) Final position** is the 2nd floor, which is $2 \times 3 = 6 \text{ m}$ above the ground floor

(i) 18 m (ii) 6 m, directed upward

Q3

2 Marks

A girl's scooter speedometer reading is constant. Is it possible for her scooter to be accelerating?

SOLUTION

- **Yes.** The speedometer shows only the **magnitude** of velocity (speed), not its direction.
- Acceleration means a change in **velocity**, and velocity changes if either the magnitude or the direction changes.
- If she rides along a curved path or takes a turn at a constant speedometer reading, the direction of her velocity changes continuously, so she is accelerating.
- This is exactly the case of uniform circular motion.

Yes — when the scooter turns, the direction of velocity changes, so it accelerates even at constant speed.

Q4

3 Marks

A car starts from rest and its velocity reaches 24 m s^{-1} in 6 s. Find the average acceleration and the distance travelled in these 6 s.

SOLUTION

- Given: $u = 0$, $v = 24 \text{ m s}^{-1}$, $t = 6 \text{ s}$
- Using $v = u + at \rightarrow 24 = 0 + a \times 6 \rightarrow a = 24/6 = 4 \text{ m s}^{-2}$
- Using $s = ut + \frac{1}{2}at^2 \rightarrow s = 0 + \frac{1}{2} \times 4 \times 6^2 = \frac{1}{2} \times 4 \times 36 = 72 \text{ m}$

$a = 4 \text{ m s}^{-2}$ in the direction of velocity; distance = 72 m

Q5

3 Marks

A motorbike with initial velocity 28 m s^{-1} and constant acceleration stops after 98 m. Find the acceleration and the time taken.

SOLUTION

- Given: $u = 28 \text{ m s}^{-1}$, $v = 0$, $s = 98 \text{ m}$
- Using $v^2 = u^2 + 2as \rightarrow 0 = 28^2 + 2a(98)$
- $0 = 784 + 196a \rightarrow a = -784/196 = -4 \text{ m s}^{-2}$
- Using $v = u + at \rightarrow 0 = 28 + (-4)t \rightarrow t = 28/4 = 7 \text{ s}$

$a = -4 \text{ m s}^{-2}$ (i.e. 4 m s^{-2} opposite to the velocity); $t = 7 \text{ s}$

Q6

2 Marks

Position–time graph of objects A and B moving on parallel tracks in the same direction (Fig. 4.27). Do A and B ever have equal velocity?

SOLUTION

- On a position–time graph, **velocity = slope** of the line.
- Two objects have equal velocity only where the **slopes of their graphs are equal**, that is, where the two lines are parallel.
- In Fig. 4.27 the two straight lines have clearly different slopes and are never parallel; they only **intersect**, which means the two objects are momentarily at the same position, not moving at the same velocity.

No — the graphs are never parallel, so their velocities are never equal.

Q7

2 Marks

Position–time graph of A and B from 0 to 10 s (Fig. 4.28). Choose the correct option(s).

(i) and (ii) are correct

REASONING

- **(i)** Both start and finish at the same positions, so their displacements over 10 s are equal; hence their average velocities are equal. Correct.
- **(ii)** Neither object reverses direction, so for each the distance covered equals the displacement. Equal distances in equal time means equal average speeds. Correct.
- **(iii)** and **(iv)** both claim unequal average speeds, which contradicts (ii). Incorrect.

Q8

3 Marks

A truck at 54 km h^{-1} slows down to 36 km h^{-1} in 36 s. Find the distance travelled during this time.

SOLUTION

- $u = 54 \text{ km h}^{-1} = 54 \times 5/18 = 15 \text{ m s}^{-1}$
- $v = 36 \text{ km h}^{-1} = 36 \times 5/18 = 10 \text{ m s}^{-1}$, $t = 36 \text{ s}$
- Using $s = \frac{1}{2}(u + v)t = \frac{1}{2}(15 + 10) \times 36$
- $s = \frac{1}{2} \times 25 \times 36 = 450 \text{ m}$

Distance travelled = 450 m

Q9

4 Marks

A car accelerates from rest to 20 m s^{-1} in 5 s, travels at 20 m s^{-1} for 10 s, then stops in 6 s. Find the total distance travelled.

SOLUTION — THREE STAGES

- **Stage 1 (accelerating):** $u = 0, v = 20, t = 5 \text{ s}$

$$s_1 = \frac{1}{2}(0 + 20) \times 5 = 50 \text{ m}$$

- **Stage 2 (uniform):** $v = 20 \text{ m s}^{-1}, t = 10 \text{ s}$

$$s_2 = 20 \times 10 = 200 \text{ m}$$

- **Stage 3 (braking):** $u = 20, v = 0, t = 6 \text{ s}$

$$s_3 = \frac{1}{2}(20 + 0) \times 6 = 60 \text{ m}$$

- Total = $50 + 200 + 60$

Total distance = 310 m

Q10

4 Marks

A bus at 36 km h^{-1} ; obstacle 30 m ahead; reaction time 0.5 s; then retardation 2.5 m s^{-2} . Will the bus stop in time?

SOLUTION

- $u = 36 \text{ km h}^{-1} = 10 \text{ m s}^{-1}$
- **Reaction distance** (bus still at 10 m s^{-1}): $s_1 = 10 \times 0.5 = 5 \text{ m}$
- **Braking distance:** $v^2 = u^2 + 2as \rightarrow 0 = 100 + 2(-2.5)s_2$
 $5s_2 = 100 \rightarrow s_2 = 20 \text{ m}$
- **Total stopping distance** = $5 + 20 = 25 \text{ m}$
- $25 \text{ m} < 30 \text{ m}$ available

Total stopping distance = 25 m. Yes, the bus stops 5 m before the obstacle.

Q11

3 Marks

"The Earth moves around the Sun." Can an object kept on the Earth be considered to be at rest?

SOLUTION

- Rest and motion are **relative** — they have meaning only with respect to a chosen reference point.
- With respect to the **Earth's surface**, the object does not change its position, so it is **at rest**.
- With respect to the **Sun**, the object travels along with the Earth at about 30 km s^{-1} , so it is very much **in motion**.
- Both statements are correct at the same time; they simply use different frames of reference.
- In everyday life we take the Earth's surface as the reference, which is why we call such an object "at rest".

Q12

4 Marks

Velocity–time graph of a cyclist from 0 s to 120 s (Fig. 4.30). Shade the regions for (i) constant velocity and (ii) decreasing velocity; calculate the displacement and the average acceleration over 120 s.

HOW TO SHADE

- **(i) Constant velocity:** shade the area under the **horizontal** portion of the graph — this rectangle is the displacement while the cyclist moves uniformly.
- **(ii) Decreasing velocity:** shade the area under the portion where the line **slopes downward** — a trapezium (or triangle) giving the displacement while she slows down.

METHOD

- **Displacement** = total area under the v–t graph = sum of the areas of the triangle, rectangle and trapezium that make up the figure.
- **Average acceleration** = (final velocity – initial velocity) ÷ total time = $\Delta v / 120$.

Displacement over 120 s = 320 m; average acceleration = $-1/60 \text{ m s}^{-2} \approx -0.017 \text{ m s}^{-2}$ (the minus sign shows the cyclist is slower at the end than at the start)

Q13

3 Marks

A runner's velocity–time graph (Fig. 4.31), velocity in km h^{-1} and time in hours. Estimate the distance she ran.

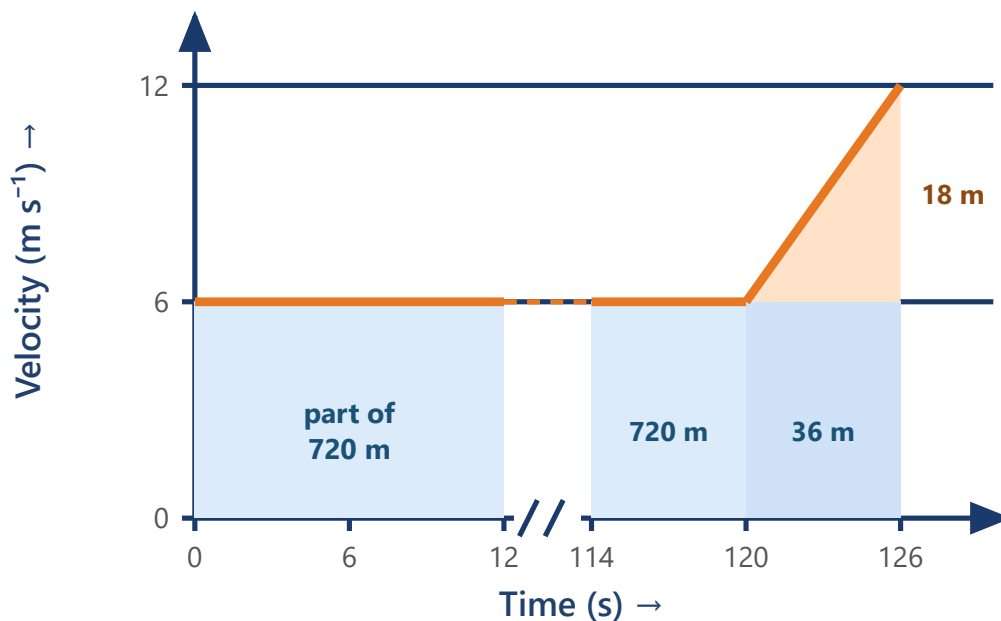
SOLUTION

- On a velocity–time graph, **distance = area under the graph**.
- Here velocity is in km h^{-1} and time in hours, so the area comes out directly in **kilometres** — no unit conversion is needed.
- Divide the figure into a triangle (while she speeds up), a rectangle (while she runs at steady speed) and a triangle (while she slows down).
- Reading the graph: she accelerates from 0 to 7.5 km h^{-1} in the first 2 h, holds 7.5 km h^{-1} for the next 2 h, then slows to rest over the last 2 h.
- Area = $\frac{1}{2} \times 2 \times 7.5 + 7.5 \times 2 + \frac{1}{2} \times 2 \times 7.5 = 7.5 + 15 + 7.5$

Estimated distance $\approx 30 \text{ km}$ (read the intercepts off your own printed graph and add the three areas the same way)

A car moves at a constant 6 m s^{-1} for 2 minutes, then accelerates at 1 m s^{-2} for 6 s. Find the displacement in 2 min 6 s by drawing a velocity–time graph.

GRAPH



The time axis is BROKEN between 12 s and 114 s (zigzag) so the last 6 s stay visible.

Because of the break the shaded blocks are not to scale — find the area by calculation.

$$\text{Displacement} = (6 \times 120) + (6 \times 6) + (\frac{1}{2} \times 6 \times 6) = 720 + 36 + 18 = 774 \text{ m}$$

Fig. 4.A — Velocity–time graph; displacement is the total area under the line

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

SOLUTION

- **Stage 1:** 2 min = 120 s at $6 \text{ m s}^{-1} \rightarrow$ rectangle of area = $6 \times 120 = 720 \text{ m}$
- **Stage 2:** $u = 6 \text{ m s}^{-1}$, $a = 1 \text{ m s}^{-2}$, $t = 6 \text{ s}$
 $s = ut + \frac{1}{2}at^2 = 6 \times 6 + \frac{1}{2} \times 1 \times 36 = 36 + 18 = 54 \text{ m}$
 (on the graph, the rectangle of 36 m plus the triangle of 18 m)
- Total displacement = $720 + 54$

Displacement = 774 m

Car A reaches 5 m s^{-1} in 5 s ; car B reaches 3 m s^{-1} in 10 s , both from rest with constant acceleration. Plot both v - t graphs and find the displacement in the two intervals.

ACCELERATIONS

- Car A: $a_A = (5 - 0)/5 = 1 \text{ m s}^{-2}$
- Car B: $a_B = (3 - 0)/10 = 0.3 \text{ m s}^{-2}$

POINTS FOR PLOTTING

t (s)	0	2	4	6	8	10
$v_A (\text{m s}^{-1})$	0	2	4	6	8	10
$v_B (\text{m s}^{-1})$	0	0.6	1.2	1.8	2.4	3.0

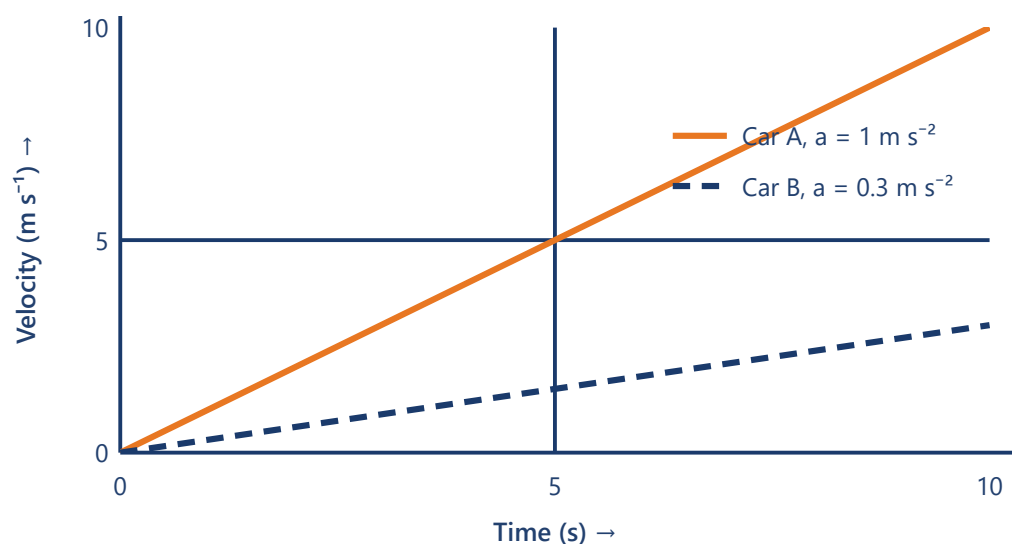


Fig. 4.B — Velocity–time graphs of cars A and B

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

DISPLACEMENTS (AREA UNDER EACH LINE)

- Car A in 5 s:** $s = \frac{1}{2} \times \text{base} \times \text{height} = \frac{1}{2} \times 5 \times 5 = 12.5 \text{ m}$
- Car B in 10 s:** $s = \frac{1}{2} \times 10 \times 3 = 15 \text{ m}$

Car A: 12.5 m in 5 s • Car B: 15 m in 10 s

Q16

4 Marks

The tip of the minute hand (length 7 cm) between 6:00 PM and 7:30 PM. Find (i) distance, (ii) displacement, (iii) speed, (iv) velocity.

SET-UP

- Time interval = 1 h 30 min = 90 min = 5400 s
- The minute hand completes one revolution in 60 min, so in 90 min it makes **1.5 revolutions**.
- $r = 7$ cm, so circumference = $2\pi r = 2 \times \frac{22}{7} \times 7 = 44$ cm

ANSWERS

- (i) **Distance** = $1.5 \times 44 = 66$ cm
- (ii) **Displacement**: after 1.5 revolutions the tip is **diametrically opposite** its starting point, so displacement = diameter = $2r = 14$ cm
- (iii) **Speed** = distance/time = $66/5400 = 11/900 \text{ cm s}^{-1} \approx 0.0122 \text{ cm s}^{-1}$
- (iv) **Velocity** = displacement/time = $14/5400 = 7/2700 \text{ cm s}^{-1} \approx 0.0026 \text{ cm s}^{-1}$, directed from the 12-mark towards the 6-mark of the dial

PART C — EXTRA QUESTIONS (SOLVED)

E1

1 Mark

The area under a velocity–time graph gives

(i) acceleration (ii) displacement (iii) speed (iv) force

(ii) displacement

E2

1 Mark

A body moves along a circular track of radius r and completes one full round. Its displacement is

(i) $2\pi r$ (ii) πr (iii) $2r$ (iv) zero

(iv) zero

E3

1 Mark

72 km h^{-1} expressed in m s^{-1} is

(i) 10 (ii) 15 (iii) 20 (iv) 25

(iii) 20

E4

1 Mark

Assertion (A): A body can have zero velocity and still be accelerating.

Reason (R): At the highest point of its flight a ball thrown upward has zero velocity but acceleration due to gravity still acts on it.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5

2 Marks

Distinguish between uniform and non-uniform motion with one example each.

SOLUTION

- **Uniform motion:** the body covers equal distances in equal intervals of time, however small the interval.
Example — a car moving on a straight road with the speedometer steady at 40 km h^{-1} .
- **Non-uniform motion:** the body covers unequal distances in equal intervals of time. Example — a bus moving through city traffic, repeatedly speeding up and slowing down.

E6

3 Marks

A train starting from rest attains a velocity of 72 km h^{-1} in 5 minutes. Assuming uniform acceleration, find (i) the acceleration and (ii) the distance travelled.

SOLUTION

- $u = 0, v = 72 \text{ km h}^{-1} = 20 \text{ m s}^{-1}, t = 5 \text{ min} = 300 \text{ s}$
- (i) $a = (v - u)/t = 20/300 = 1/15 \approx 0.067 \text{ m s}^{-2}$
- (ii) $s = \frac{1}{2}(u + v)t = \frac{1}{2} \times 20 \times 300 = 3000 \text{ m} = 3 \text{ km}$

$a = 0.067 \text{ m s}^{-2}; s = 3000 \text{ m}$

E7

3 Marks

A car travels the first half of a journey at 30 km h^{-1} and the second half at 60 km h^{-1} . Find its average speed for the whole journey.

SOLUTION

- Let each half be d km, so total distance = $2d$.
- Time for first half = $d/30$ h; time for second half = $d/60$ h
- Total time = $d/30 + d/60 = (2d + d)/60 = 3d/60 = d/20$ h
- Average speed = total distance / total time = $2d \div (d/20) = 40 \text{ km h}^{-1}$

Average speed = 40 km h^{-1} (note: **not** 45, the plain average of 30 and 60)

E8

3 Marks

A stone is dropped from a tower and reaches the ground in 4 s. Taking $g = 10 \text{ m s}^{-2}$, find the height of the tower and the velocity with which it strikes the ground.

SOLUTION

- $u = 0$, $a = g = 10 \text{ m s}^{-2}$, $t = 4 \text{ s}$
- Height: $s = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2} \times 10 \times 16 = 80 \text{ m}$
- Final velocity: $v = u + at = 0 + 10 \times 4 = 40 \text{ m s}^{-1}$

Height = 80 m ; striking velocity = 40 m s^{-1} downward

E9

3 Marks

A body covers 20 m in the 3rd second and 30 m in the 5th second of its uniformly accelerated motion. Find u and a .

SOLUTION

- Distance in the n^{th} second: $s_n = u + a(2n - 1)/2$
- 3rd second: $u + 5a/2 = 20 \dots(1)$
- 5th second: $u + 9a/2 = 30 \dots(2)$
- $(2) - (1)$: $2a = 10 \rightarrow a = 5 \text{ m s}^{-2}$
- From (1): $u = 20 - 12.5 = 7.5 \text{ m s}^{-1}$

$u = 7.5 \text{ m s}^{-1}$; $a = 5 \text{ m s}^{-2}$

E10**4 Marks**

Case study: A school bus starts from rest, accelerates uniformly for 10 s to reach 15 m s^{-1} , maintains this speed for 40 s, and then decelerates uniformly to rest in 5 s. (i) Draw the shape of the v - t graph. (ii) Find the acceleration in the first and last stages. (iii) Find the total distance covered. (iv) Find the average speed.

SOLUTION

- (i) The graph is a **trapezium** — a straight line rising from the origin to 15 m s^{-1} at $t = 10 \text{ s}$, a horizontal line up to $t = 50 \text{ s}$, and a steeper line falling to zero at $t = 55 \text{ s}$.
- (ii) First stage: $a = (15 - 0)/10 = 1.5 \text{ m s}^{-2}$. Last stage: $a = (0 - 15)/5 = -3 \text{ m s}^{-2}$.
- (iii) $s_1 = \frac{1}{2} \times 10 \times 15 = 75 \text{ m}$; $s_2 = 15 \times 40 = 600 \text{ m}$; $s_3 = \frac{1}{2} \times 5 \times 15 = 37.5 \text{ m}$.
Total = $75 + 600 + 37.5 = 712.5 \text{ m}$
- (iv) Total time = $10 + 40 + 5 = 55 \text{ s}$. Average speed = $712.5/55 \approx 12.95 \text{ m s}^{-1}$

E11**5 Marks**

Derive the three equations of motion graphically for a body moving with uniform acceleration a , initial velocity u and final velocity v after time t .

SET-UP

- On a velocity-time graph, the motion is the straight line AB, with OA = u at $t = 0$ and BC = v at time t . OC = t along the time axis. Draw AD parallel to OC, so BD = $v - u$.

FIRST EQUATION: $V = U + AT$

- Acceleration = slope of AB = $BD/AD = (v - u)/t$
- $\rightarrow at = v - u \rightarrow \mathbf{v = u + at}$

SECOND EQUATION: $S = UT + \frac{1}{2}AT^2$

- Displacement = area of trapezium OABC = area of rectangle OADC + area of triangle ADB
- $= (u \times t) + \frac{1}{2} \times t \times (v - u) = ut + \frac{1}{2} \times t \times at$
- $\rightarrow \mathbf{s = ut + \frac{1}{2}at^2}$

THIRD EQUATION: $V^2 = U^2 + 2AS$

- Area of trapezium = $\frac{1}{2}(\text{sum of parallel sides}) \times \text{height} = \frac{1}{2}(u + v) \times t$
- From the first equation, $t = (v - u)/a$
- $s = \frac{1}{2}(u + v) \times (v - u)/a = (v^2 - u^2)/2a$
- $\rightarrow \mathbf{v^2 = u^2 + 2as}$

CHAPTER 5

Exploring Mixtures and their Separation

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit II — Matter, Its Nature and Behaviour (25 marks)**, shared with Chapters 8 and 9. Concentration calculations, the separation-technique table and the Tyndall effect are near-certain question sources. Labelled diagrams of distillation and separating funnel are commonly asked for 3 marks.

5.1 Classifying mixtures

Mixture: two or more substances mixed in any proportion, each retaining its own properties, separable by physical means.

Homogeneous mixture	Heterogeneous mixture
Uniform composition throughout	Composition varies from part to part
No visible boundaries between components	Components visibly separate or in distinct phases
Examples: air, sugar solution, salt solution, brass, bronze, vinegar, copper sulfate solution	Examples: muddy water, milk, blood, smoke, fog, sand in water, oil and water

5.2 Solutions, suspensions and colloids

Property	Solution	Colloid	Suspension
Particle size	Less than 1 nm	1–1000 nm	More than 1000 nm
Nature	Homogeneous	Appears homogeneous, actually heterogeneous	Heterogeneous
Appearance	Transparent	Translucent	Opaque
Settles on standing?	Never	Never (stays evenly distributed)	Yes, settles down
Filtration	Cannot be separated	Cannot be separated by ordinary filter paper (needs centrifugation)	Can be separated by filtration
Tyndall effect	Does not show	Shows	Shows
Examples	Salt solution, brass, air	Milk, butter, smoke, fog, blood, ink	Mud in water, chalk in water, sand in water

Tyndall effect: the scattering of a beam of light by the dispersed particles of a colloid or suspension, which makes the path of the beam visible. Solutions do not show it because their particles are too small (< 1 nm) to scatter light. Everyday examples: sunlight streaming through a canopy of leaves or through a gap in a dusty room; a torch beam in fog.

Parts of a solution: the **solute** is the dissolved substance (usually the smaller amount); the **solvent** is the dissolving medium (usually the larger amount). Water is the universal solvent. In a colloid, the two parts are called the **dispersed phase** and the **dispersion medium**.

12 Concentration — the calculations

$$\text{Mass percentage (\% m/m)} = (\text{mass of solute} \div \text{mass of solution}) \times 100$$

$$\text{Volume percentage (\% v/v)} = (\text{volume of solute} \div \text{volume of solution}) \times 100$$

$$\text{Mass by volume (\% m/v)} = (\text{mass of solute in g} \div \text{volume of solution in mL}) \times 100$$

The commonest slip is using the mass of the **solvent** in the denominator instead of the mass of the **solution**. Mass of solution = mass of solute + mass of solvent.

Saturation and solubility

- **Unsaturated solution** — can still dissolve more solute at that temperature.
- **Saturated solution** — has dissolved the maximum amount of solute possible at that temperature.
- **Solubility** — the mass of solute that saturates 100 g of solvent at a given temperature.
- For most solids, solubility **increases** with temperature; for gases, it **decreases** with temperature (warm cola goes flat).
- Cooling a hot saturated solution makes the excess solute separate out as **crystals**.



5.3–5.4 Methods of separation

Method	Property used	Typical mixture
Filtration	Difference in particle size	Mud from muddy water; tea leaves from tea
Sedimentation & decantation	Difference in density; insolubility	Sand and water
Centrifugation	Density difference, accelerated by rapid spinning	Plasma from blood cells; cream from milk
Coagulation	Small particles made to clump with a coagulant, then settle	Alum added to muddy water
Evaporation	Solvent is volatile, solute is not	Salt from sea water; recovering dye
Crystallisation	Solubility falls on cooling	Purifying copper sulfate, alum, sugar
Sublimation	One component sublimates on heating	Camphor, naphthalene, ammonium chloride, iodine from sand or salt
Simple distillation	Difference in boiling points	Water from salt water; acetone from water
Fractional distillation	Boiling points differ by less than 25 °C	Components of petroleum; separating gases of liquid air
Separating funnel	Immiscibility and different densities	Oil and water; kerosene and water
Chromatography	Different rates of movement on the paper	Pigments in ink, in a flower, in a food colour
Magnetic separation	One component is magnetic	Iron filings from sulfur

Sublimation = solid → vapour directly, without melting. **Deposition** = vapour → solid directly, without condensing.

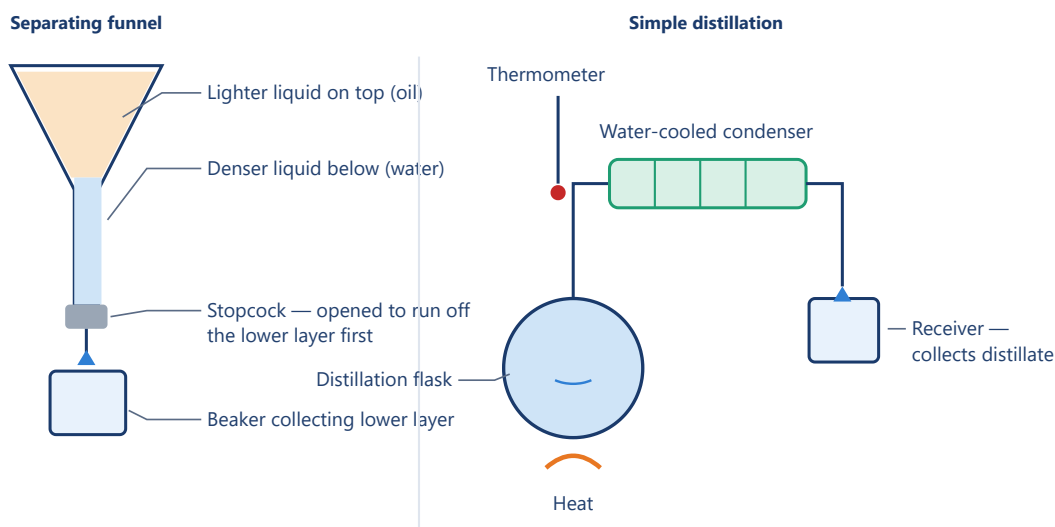


Fig. 5.A — Separating funnel and simple distillation apparatus, fully labelled (schematic)

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINER)

Q1

1 Mark

Which of the following mixtures are correctly classified as homogeneous (Hm) and heterogeneous (Ht)?

(iv) Muddy water — Ht, Milk — Ht, Blood — Ht, Brass — Hm

WHY THE OTHERS FAIL

- (i) Smoke is heterogeneous (a colloid of solid particles in gas), not homogeneous.
- (ii) Brass and vinegar are homogeneous, and muddy water is heterogeneous — every label is reversed.
- (iii) Milk is heterogeneous (a colloid), not homogeneous.

Q2

2 Marks

Which mixtures show the Tyndall effect? (a) air and dust (b) copper sulfate and water (c) starch and water (d) acetone and water

(iii) a and c

REASONS

- **(a) Air and dust** — dust particles are large enough to scatter light, so the beam becomes visible. Shows the effect.
- **(c) Starch and water** — a colloid; the starch particles (1–1000 nm) scatter light. Shows the effect.
- **(b) Copper sulfate solution** — a true solution; particles below 1 nm are far too small to scatter light. Does not show it.
- **(d) Acetone and water** — miscible liquids forming a true solution. Does not show it.

Q3

3 Marks

Complete Table 5.2 for solution, suspension and colloid.

COMPLETED TABLE

	Solution	Suspension	Colloid
Properties	Small-sized particles (less than 1 nm diameter); particles remain evenly distributed; does not settle down; transparent; cannot be separated by filtration	Large-sized particles; settles down when left undisturbed (more than 1000 nm in diameter); separates by filtration; heterogeneous mixture; scatters light	Moderate-sized particles (1–1000 nm); particles remain evenly distributed; does not settle down; scatters light; cannot be separated by filtration; heterogeneous mixture
Examples	Salt solution; brass	Sand in water; mud	Milk; smoke; butter

Q4

4 Marks

- (i) A cake recipe uses 75 g sugar, 420 g flour and 5 g sodium hydrogencarbonate. Express the concentration of each.
- (ii) A brass alloy is 70% copper by mass; find copper and zinc in 120 g of brass.

(I) SOLUTION

- The components are all solids, so **mass percentage (% m/m)** is the appropriate method.
- Total mass of mixture = $75 + 420 + 5 = 500$ g
- Sugar = $(75/500) \times 100 = 15\%$
- Flour = $(420/500) \times 100 = 84\%$
- Sodium hydrogencarbonate = $(5/500) \times 100 = 1\%$
- Check: $15 + 84 + 1 = 100$ ✓

(II) SOLUTION

- Mass of copper = 70% of 120 g = $(70/100) \times 120 = 84$ g
- Mass of zinc = $120 - 84 = 36$ g

Q5

3 Marks

One litre of cooking oil has a mass of 910 g. If mixed with water, will it form a separate layer? Which will be on top? How will you separate them? Draw the apparatus.

SOLUTION

- **Yes, a separate layer forms.** Oil and water are **immiscible** — they do not dissolve in each other.
- Density of oil = $910 \text{ g} \div 1000 \text{ mL} = 0.91 \text{ g mL}^{-1}$, which is **less than** the density of water (1.0 g mL^{-1}).
- Therefore the **oil floats on top** and water forms the lower layer.
- **Method of separation: a separating funnel.** Pour the mixture in, let it stand until two clear layers form, open the stopcock and run off the lower water layer into a beaker, then close the stopcock the moment the boundary reaches it, and collect the oil separately.
- The apparatus is shown in Fig. 5.A above — a pear-shaped funnel on a stand, with the lighter oil labelled above and the denser water below, and the stopcock at the bottom.

Q6

1 Mark

Assertion (A): Solutions do not exhibit the Tyndall effect. Reason (R): The particles in solutions are larger than 100 nm, so they cannot scatter light.

(iii) A is true, but R is false

EXPLANATION

- The assertion is correct — true solutions do not scatter light.
- But the reason is wrong twice over: solution particles are **smaller** than 1 nm, not larger than 100 nm; and it is precisely because they are so small that they cannot scatter light.

Q7

5 Marks

How would you separate the mixtures in Table 5.3? Give the reason for each choice.

COMPLETED TABLE

Mixture	Method	Reason for selection
Mud from muddy water	Filtration (or sedimentation and decantation)	Mud is insoluble and its particles are larger than the pores of filter paper
Plasma from other components of blood	Centrifugation	Blood cells are denser than plasma; rapid spinning forces them to the bottom, and they are too small for filtration
Naphthalene and sand	Sublimation	Naphthalene sublimes on gentle heating while sand does not
Chalk powder and common salt	Dissolve in water, filter, then evaporate the filtrate	Salt is soluble in water, chalk is not; the salt is recovered from the filtrate by evaporation
Common salt and water	Evaporation (or distillation if the water is also wanted)	Water is volatile and salt is not; distillation recovers both components
Oil from water	Separating funnel	The liquids are immiscible and differ in density
Pigments of a flower	Paper chromatography	The pigments are soluble but move at different rates on the paper, so they separate into bands

Q8

3 Marks

Two miscible liquids A (b.p. 60 °C) and B (b.p. 90 °C) are mixed. Suggest a method of separation and draw a labelled diagram.

SOLUTION

- The liquids are **miscible** and their boiling points differ by $90 - 60 = 30\text{ °C}$, which is more than 25 °C .
- Therefore **simple distillation** is sufficient (fractional distillation would be needed only if the gap were less than 25 °C).
- Procedure:** place the mixture in a distillation flask with a thermometer whose bulb is level with the side-arm. Heat slowly. At 60 °C liquid A boils; its vapour passes into the water-cooled condenser, condenses and is collected as the first distillate. The thermometer holds steady at 60 °C until all of A has distilled over, then rises. Change the receiver and collect B at 90 °C .
- The labelled apparatus is shown in Fig. 5.A — distillation flask, thermometer, condenser with water inlet and outlet, receiver, and heat source.

Q9

4 Marks

Compare evaporation, crystallisation and distillation. In which situation would you prefer each?

COMPARISON

Point	Evaporation	Crystallisation	Distillation
Principle	The volatile solvent escapes as vapour on heating	Solubility falls on cooling, so pure solute separates as crystals	Difference in boiling points; the vapour is condensed back
What is recovered	The solute only	Pure crystals of the solute	Both components
Purity	Impurities remain mixed with the solute	Highest purity — impurities stay in the mother liquor	High purity of the distillate
Suitable for	Heat-stable solutes	Solutes that decompose on strong heating, e.g. sugar	Miscible liquids, or when the solvent is valuable

WHEN TO PREFER EACH

- **Evaporation** — when only the solute is wanted and the solvent is cheap: obtaining common salt from sea water; recovering dye from an ink solution.
- **Crystallisation** — when a **pure** solid is wanted or when the solid would decompose on strong heating: purifying copper sulfate, alum or sugar.
- **Distillation** — when **both** components are needed, or when separating miscible liquids: obtaining drinking water from sea water, separating acetone from water.

Q10

3 Marks

Blood is a colloidal mixture. (i) What would happen if blood behaved like a true suspension inside the body? (ii) Identify the dispersed phase and dispersion medium in a blood sample.

SOLUTION

- **(i)** In a suspension the particles are large and **settle down** when undisturbed. If blood behaved this way, the cells would settle in the vessels instead of staying evenly distributed. This would
 - block capillaries and arteries, causing clots;
 - stop the uniform transport of oxygen, nutrients, hormones and wastes;
 - starve tissues of oxygen and prove fatal.
 Because blood is a colloid, its cells stay evenly dispersed and circulate freely.
- **(ii) Dispersed phase** = the blood cells (red cells, white cells) and platelets, together with suspended proteins and fat globules. **Dispersion medium** = **plasma**, the straw-coloured fluid.

Q11

3 Marks

A mixture of sand, common salt and naphthalene (Fig. 5.25). Write the correct sequence of separation techniques.

CORRECT SEQUENCE

- **Step 1 — Sublimation.** Heat the mixture gently in a china dish covered by an inverted funnel. Naphthalene sublimates and deposits on the cool inner surface of the funnel, and is collected. Sand and salt remain behind.
- **Step 2 — Dissolution and filtration.** Add water to the residue and stir. The salt dissolves; the sand does not. Filter the mixture: sand stays on the filter paper as residue, salt solution passes through as filtrate.
- **Step 3 — Evaporation (or crystallisation).** Heat the filtrate to evaporate the water and recover the common salt.
- **Sequence in short:** Sublimation → Filtration → Evaporation.
- **Why this order:** naphthalene must be taken out first, because it is insoluble in water and would otherwise be left mixed with the sand.

Q12

2 Marks

Why is distillation an effective method for separating a mixture of water and acetone?

SOLUTION

- Water and acetone are **miscible**, so they cannot be separated by a separating funnel or by filtration.
- Their boiling points are widely apart — acetone boils at 56 °C and water at 100 °C, a difference of 44 °C, well over the 25 °C needed for simple distillation.
- On heating, acetone vaporises first and is condensed and collected separately, leaving water behind; both components are recovered pure.

Q13

4 Marks

Using the solubility data of Table 5.4, answer (i), (ii) and (iii).

(I) POTASSIUM NITRATE NEEDED FOR A SATURATED SOLUTION IN 50 G WATER AT 40 °C

- From the table, solubility of KNO_3 at 40 °C = 62 g per 100 g of water.
- For 50 g of water: mass = $62 \times (50/100) = 31 \text{ g}$

(II) SATURATED KCL SOLUTION MADE AT 80 °C AND COOLED TO 25 °C

- Solubility of KCl at 80 °C = 54 g per 100 g of water; at about 25 °C it is only about 35–37 g per 100 g of water.
- As the solution cools it can no longer hold all the dissolved salt, so it becomes **supersaturated**.
- The excess — roughly 17–19 g per 100 g of water — separates out as **crystals of potassium chloride** at the bottom of the vessel.
- This is exactly the principle of **crystallisation**.

(III) EFFECT OF TEMPERATURE ON SOLUBILITY

- For all four salts the solubility **increases** as temperature rises, but by very different amounts.
- Potassium nitrate** — from 21 to 167 g, an increase of 146 g. By far the steepest rise; most strongly affected by temperature.
- Ammonium chloride** — from 24 to 66 g, an increase of 42 g. A moderate rise.
- Potassium chloride** — from 35 to 54 g, an increase of 19 g. A small rise.
- Sodium chloride** — from 36 to 37 g, an increase of only 1 g. Almost unaffected by temperature, which is why common salt cannot be purified easily by crystallisation on cooling.

Q14

3 Marks

Student A: 20 g sugar in 80 g water. Student B: 20 g sugar in 100 g water. Student C: 30 g sugar in 80 g water. (i) Find % m/m for each. (ii) Whose solution is most concentrated?

(I) CALCULATIONS

- Student A:** mass of solution = 20 + 80 = 100 g $\rightarrow (20/100) \times 100 = 20\%$
- Student B:** mass of solution = 20 + 100 = 120 g $\rightarrow (20/120) \times 100 = 16.67\%$
- Student C:** mass of solution = 30 + 80 = 110 g $\rightarrow (30/110) \times 100 = 27.27\%$

(II) ANSWER

- Student C's solution is the most concentrated.**
- C uses the largest amount of sugar (30 g) in the smallest amount of water (80 g), so the sugar forms the greatest fraction of the total mass.
- Comparing A and B shows that adding more solvent to the same solute **dilutes** the solution; comparing A and C shows that adding more solute to the same solvent **concentrates** it.

Examine Fig. 5.26. (i) Identify technique S. (ii) Label apparatus A, B and C. (iii) Which of the listed mixtures can be separated by this technique, using Table 5.5?

SOLUTION

- **(i) Technique S: Fractional distillation** (the fractionating column packed with glass beads is the giveaway; simple distillation has no such column).
- **(ii) Labels: A** — fractionating column (packed with glass beads to give a large surface for repeated condensation and vaporisation); **B** — condenser (water-jacketed, cools the vapour back to liquid); **C** — receiver or conical flask that collects the distillate. The flask below A is the distillation flask and carries the thermometer.
- **(iii)** Fractional distillation is used when the boiling points of two miscible liquids differ by **less than 25 °C**. From Table 5.5: water 100, acetone 56, alcohol 78, chloroform 61, benzene 80 °C.

Mixture	Difference in b.p.	Separable by fractional distillation?
(a) water – acetone	44 °C	No — simple distillation suffices
(b) water – salt	—	No — a solid in a liquid; use evaporation
(c) acetone – alcohol	22 °C	Yes
(d) sand – salt	—	No — two solids; use dissolution and filtration
(e) alcohol – chloroform	17 °C	Yes
(f) alcohol – benzene	2 °C	Yes

- So (c), (e) and (f) can be separated by fractional distillation.

PART C — EXTRA QUESTIONS (SOLVED)

Which of the following is a colloid?

(i) Sugar solution (ii) Milk (iii) Sand in water (iv) Brass

(ii) Milk

E2

1 Mark

A mixture of iodine and sand is best separated by
(i) filtration (ii) distillation (iii) sublimation (iv) chromatography

(iii) sublimation

E3

1 Mark

The technique used to separate cream from milk is
(i) filtration (ii) centrifugation (iii) evaporation (iv) decantation

(ii) centrifugation

E4

1 Mark

Assertion (A): A beam of light is visible when it passes through fog.
Reason (R): Fog is a colloid and its dispersed water droplets scatter light.
(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5

2 Marks

Calculate the mass percentage of a solution made by dissolving 25 g of common salt in 175 g of water.

SOLUTION

- Mass of solution = $25 + 175 = 200$ g
- % m/m = $(25/200) \times 100 = 12.5\%$

Mass percentage = 12.5%

E6

2 Marks

Why is alum added to muddy water before drinking? Name the process.

SOLUTION

- Alum acts as a **coagulant**: it neutralises the charges on the fine suspended clay particles so that they clump together into larger, heavier masses.
- These heavier clumps settle quickly at the bottom and the clear water can be decanted or filtered. The process is called **coagulation (flocculation)**.

E7**2 Marks**

Why can a colloid not be separated by ordinary filtration, though it is heterogeneous?

SOLUTION

- Colloidal particles are only 1–1000 nm across — much smaller than the pores of filter paper — so they pass straight through with the filtrate.
- They also never settle on standing, so sedimentation does not help; centrifugation is used instead.

E8**3 Marks**

How would you obtain pure copper sulfate crystals from an impure sample? Why is crystallisation preferred over simple evaporation here?

PROCEDURE

- Dissolve the impure copper sulfate in the minimum quantity of warm water containing a few drops of dilute sulfuric acid.
- Filter the hot solution to remove insoluble impurities.
- Allow the filtrate to cool slowly and undisturbed. Blue crystals of copper sulfate separate out.
- Filter, wash with a little cold water, and dry the crystals between filter papers.

WHY CRYSTALLISATION IS PREFERRED

- Evaporating to dryness would leave every soluble impurity behind along with the salt.
- In crystallisation the impurities stay behind dissolved in the mother liquor, so the crystals obtained are far purer; the salt is also not damaged by strong heating.

E9**3 Marks**

A student is given a mixture of iron filings, sulfur powder and common salt. Describe how each component can be separated.

SOLUTION

- **Step 1 — Magnetic separation:** move a bar magnet over the mixture; the iron filings cling to it and are removed.
- **Step 2 — Dissolution and filtration:** add water to the remaining sulfur and salt. Salt dissolves; sulfur does not. Filter — sulfur is the residue.
- **Step 3 — Evaporation:** heat the filtrate to evaporate the water and recover the common salt.

E10**3 Marks**

The solubility of a salt is 40 g per 100 g of water at 60 °C. A student dissolves 50 g of the salt in 100 g of water at 60 °C. What will she observe, and what mass of salt stays undissolved?

SOLUTION

- At 60 °C only 40 g can dissolve in 100 g of water — that is the saturation limit.
- The extra $50 - 40 = 10$ g cannot dissolve and will be seen lying undissolved at the bottom of the beaker.
- The solution above it is a **saturated solution** at 60 °C. On further heating, more salt would dissolve, since solubility of solids rises with temperature.

E11**4 Marks**

Case study: A village gets water from a pond. The water is muddy, has a slight smell, and is suspected to contain dissolved salts and microbes. Suggest a step-by-step treatment, naming the principle at each step.

SOLUTION

- **1. Sedimentation and decantation** — let the water stand so that heavy suspended matter settles by gravity, and pour off the clear water.
- **2. Coagulation with alum** — fine clay particles that will not settle are clumped together by the coagulant and then removed.
- **3. Filtration** — through sand and gravel beds or cloth; removes remaining suspended solids on the basis of particle size.
- **4. Boiling or chlorination** — kills microbes; chlorination works chemically rather than by separation.
- **5. Distillation** (only if dissolved salts must also be removed) — the water is vaporised and condensed, leaving all non-volatile dissolved solids behind.
- **Note:** filtration alone removes only suspended matter, never dissolved salts — that is why step 5 is needed for genuinely pure water.

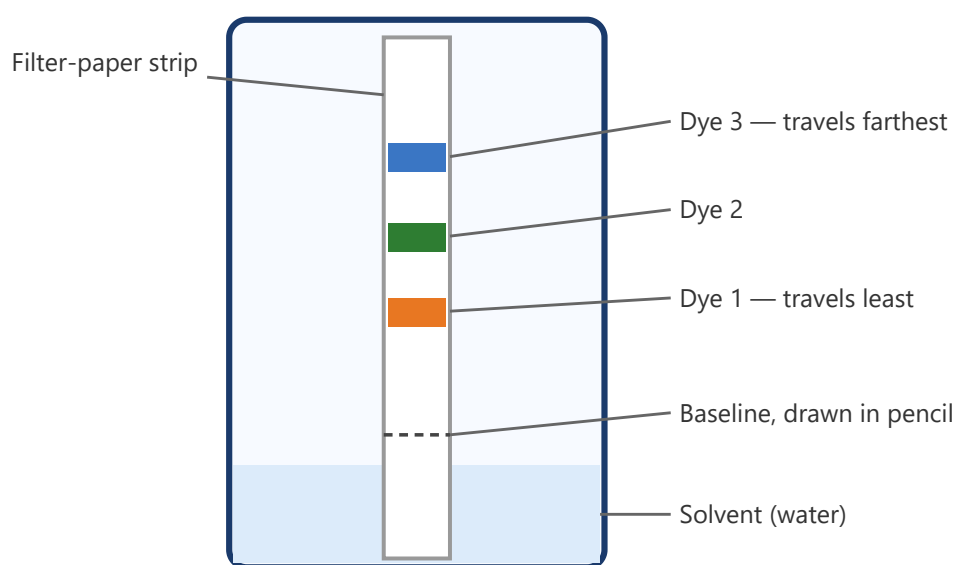
Describe the process of paper chromatography used to separate the dyes in black ink. Draw a labelled sketch and state the principle.

PRINCIPLE

- Different components of a mixture are adsorbed to different extents on the paper and are carried along at different rates by the solvent, so they separate into distinct bands.

PROCEDURE

- Take a strip of filter paper and draw a pencil line about 3 cm from one end — the **baseline**.
- Put a small drop of black ink on the baseline and let it dry; repeat two or three times to concentrate the spot.
- Suspend the strip in a jar so that the lower edge dips in water, but the **ink spot stays above the water level**.
- Water rises up the paper by capillary action, carrying the dyes with it.
- After some time the dyes appear as separate coloured bands at different heights. Dry the strip — this is the **chromatogram**.



The ink spot must stay above the solvent level

Fig. 5.B — Separation of the dyes in ink by paper chromatography

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

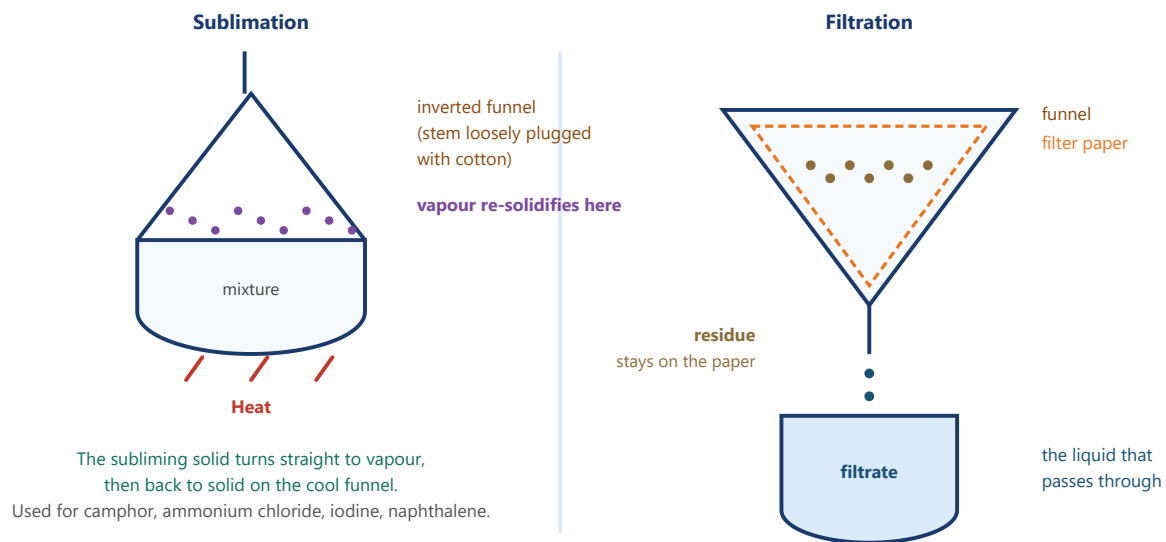


Fig. 5.C — Sublimation and filtration: the two set-ups asked most often

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

USES

- Separating pigments from a flower or leaf; testing the purity of a food colour; detecting drugs in blood or urine.

CHAPTER 6

How Forces Affect Motion

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit III — Motion, Force, Work and Sound (23 marks)**. Newton's laws are the single most heavily examined topic of the unit: expect one numerical on $F = ma$, one conceptual question on inertia or the third law, and often a graph-based question.

6.1–6.3 Force, balanced and unbalanced forces, friction

Force is a push or a pull. It can (i) change the state of rest or motion, (ii) change the speed, (iii) change the direction of motion, and (iv) change the shape or size of a body. SI unit: **newton (N)**. It is a vector.

- **Balanced forces:** the net force is zero. The state of motion does **not** change — a body at rest stays at rest, a moving body continues at constant velocity. Balanced forces can still change the **shape** of a body.
- **Unbalanced forces:** the net force is not zero, so the body accelerates in the direction of the net force.
- Forces along the same line: add if in the same direction, subtract if opposite.

Friction

- **Friction** is the force that opposes relative motion between two surfaces in contact; it always acts **opposite to the direction of motion** (or of attempted motion).
- It arises from the interlocking of irregularities on the two surfaces.
- It depends on the **nature of the surfaces** and on **how hard they press together**, but not appreciably on the area of contact.
- **Static friction > sliding friction > rolling friction.** This is why it is harder to start a box moving than to keep it moving, and why wheels were such an important invention.
- **Reducing friction:** lubricants, ball bearings, polishing, streamlining, magnetic levitation. **Increasing friction:** treads on tyres and shoes, brake pads, grooved handles.
- Friction is a **necessary evil** — it wastes energy as heat and wears out parts, but without it we could not walk, write or stop a vehicle.

6.4 Newton's First Law — the law of inertia

An object at rest remains at rest, and an object in motion continues to move with constant velocity, unless a net force acts on it.

- **Inertia** is the natural tendency of a body to resist a change in its state of rest or of uniform motion.
- **Mass is the measure of inertia** — the greater the mass, the greater the inertia.
- **Inertia of rest:** passengers fall backward when a bus starts suddenly; dust comes out when a carpet is beaten.
- **Inertia of motion:** passengers lurch forward when a bus brakes suddenly; an athlete runs some distance past the finishing line.
- **Inertia of direction:** mud flies off tangentially from a spinning wheel; a passenger leans outward when the vehicle turns.

6.5 Newton's Second Law

$$F = ma \quad \bullet \quad a = F/m \quad \bullet \quad F = m(v - u)/t$$

- The acceleration is **in the direction of the net force, directly proportional** to it, and **inversely proportional** to the mass.
- **1 newton** is the force that gives a mass of 1 kg an acceleration of 1 m s^{-2} .
- The second law explains why increasing the **time of impact** reduces the force: since $F = m(v - u)/t$, a longer t for the same change of velocity means a smaller F . This is the principle behind landing mats, air bags, crumple zones, and a cricketer pulling his hands back while catching a ball.

⇌ 6.6 Newton's Third Law

To every action there is an equal and opposite reaction. The two forces act on **two different bodies**.

- Because they act on different bodies, action and reaction **never cancel each other**.
- Examples: walking (foot pushes ground back, ground pushes foot forward); a swimmer pushing water backward; recoil of a gun; a rocket ejecting hot gases; a boat moving back when a sailor jumps forward.
- The forces are equal, but the **accelerations are not**, because the two bodies usually have very different masses — $a = F/m$.

6.7 Systems of objects

- When two or more bodies move together, they can be treated as a **single system** of mass $(m_1 + m_2)$, acted on only by the **external** forces.
- Internal forces (such as the tension in a connecting string) are action–reaction pairs within the system and cancel out.
- Acceleration of the system: $a = F_{\text{external}} / (m_1 + m_2)$.
- To find the internal force, apply $F = ma$ to one body alone afterwards.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

2 Marks

A table is moved across the floor at constant velocity by a horizontal force F . How much is the frictional force exerted by the floor on the table?

SOLUTION

- The table moves with **constant velocity**, so its acceleration is zero.
- By Newton's second law, zero acceleration means the **net force is zero**, so the forces must be balanced.
- Hence the frictional force is equal in magnitude to F and acts in the opposite direction to the applied force.

Frictional force = F , directed opposite to the applied force

Q2

3 Marks

For a ball on a smooth frictionless surface, choose the correct option in each statement.

SOLUTION

- (i) No net force $\rightarrow$ the velocity will **remain the same** (Newton's first law).
- (ii) Net force in the direction of motion $\rightarrow$ the magnitude of velocity will **increase**.
- (iii) Net force opposite to the motion $\rightarrow$ the magnitude of velocity will **decrease**.

Q3

1 Mark

Block P has 4 N and 5 N acting in opposite directions; block Q moves with constant velocity. Which statement is correct?

(i) P experiences a net force and Q does not experience a net force.

REASONING

- For P : net force = $5 - 4 = 1\text{ N}$, which is not zero, so P experiences a net force and accelerates.
- For Q : it moves with constant velocity, so its acceleration is zero, which means the net force on it is zero.

Q4

3 Marks

In a snake-boat race 100 oarsmen row; 95 row so as to drive the boat forward and 5 row in the opposite direction. Each applies 200 N. Find the net force on the boat.

SOLUTION

- Forward force = $95 \times 200 = 19,000 \text{ N}$
- Backward force = $5 \times 200 = 1,000 \text{ N}$
- These act along the same line in opposite directions, so they subtract.
- Net force = $19,000 - 1,000 = 18,000 \text{ N}$

Net force = 18,000 N in the forward direction

Q5

1 Mark

When a net force acts on an object, the object accelerates ...

(iv) in the direction of the force, with acceleration proportional to the force acting on the object

REASON

- From $F = ma$, $a \propto F$ for a fixed mass, and the acceleration is along the direction of the net force.
- Options (i) and (ii) wrongly reverse the direction; (iii) wrongly makes a inversely proportional to F instead of to m .

Q6

1 Mark

Position–time graphs of four objects A, B, C and D (Fig. 6.37). A net force acts on which object?

(iii) Object C

REASONING

- A net force produces acceleration, and accelerated motion gives a **curved** position–time graph.
- Straight-line $x-t$ graphs (whether horizontal or sloping) mean rest or uniform velocity, hence zero net force.
- Only the graph of object C is curved, so only C is accelerating.

Q7

3 Marks

A sailor jumps forward from a small boat to the shore. Will the boat move? In which direction and why?

SOLUTION

- **Yes, the boat moves — backward**, i.e. away from the shore.
- To jump forward, the sailor pushes the boat **backward** with his feet (the action force).
- By Newton's third law, the boat pushes the sailor **forward** with an equal and opposite force (the reaction), which launches him toward the shore.
- The backward force on the boat is unbalanced, since water offers little resistance, so the boat accelerates backward.
- The boat's backward speed is much smaller than the sailor's forward speed because the boat is heavier ($a = F/m$), though for a very light boat the effect is large — which is why jumping from a small boat is risky.

Q8

3 Marks

Why is a landing mat or sand bed placed for a high jumper?

SOLUTION

- The athlete lands with a certain velocity, and that velocity has to be reduced to zero in every case.
- From Newton's second law, $F = m(v - u)/t$ — the force depends on **how long** the stopping takes.
- A soft mat or sand compresses and **increases the time of impact** t .
- Since the change of momentum is fixed, a larger t means a much **smaller force** on the athlete's body.
- The mat also spreads the force over a larger area of the body, reducing the pressure and the risk of fracture. Landing on a hard floor would stop the athlete almost instantly, producing a very large force and injury.

Q9

1 Mark

A loaded hand cart collides with an identical but empty hand cart. During the collision:

(iv) the loaded cart and the empty cart both exert an equal magnitude of force on each other

REASON

- Newton's third law applies to every interaction regardless of the masses involved.
- The forces are equal and opposite; only the **accelerations** differ, the lighter empty cart being accelerated much more.

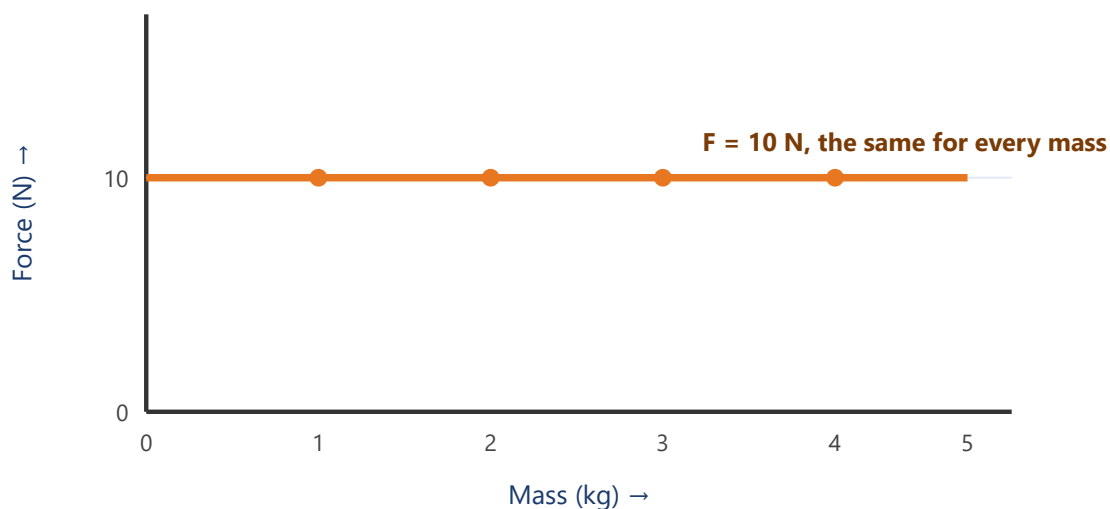
Q10

3 Marks

From the acceleration–mass graph (Fig. 6.40), plot the force–mass graph.

SOLUTION

- The same force acts on objects of different masses, so from $F = ma$ the acceleration falls as the mass rises — the a – m graph is a hyperbola ($a \propto 1/m$).
- Read any pair from the graph: for example $m = 2 \text{ kg}$ with $a = 5 \text{ m s}^{-2}$ gives $F = 10 \text{ N}$; $m = 4 \text{ kg}$ with $a = 2.5 \text{ m s}^{-2}$ also gives $F = 10 \text{ N}$.
- Since the product $m \times a$ is the same at every point, the force is **constant at 10 N** for all masses.
- Therefore the force–mass graph is a **straight horizontal line** at $F = 10 \text{ N}$, parallel to the mass axis.



Since $m \times a = 10$ at every point, the force–mass graph is a horizontal straight line

Fig. 6.A — Force–mass graph derived from the acceleration–mass data

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Q11

3 Marks

From the velocity–time graph of a 10 kg object (Fig. 6.41), calculate the force acting on it.

SOLUTION

- On a velocity–time graph, **acceleration = slope**.
- Reading the graph: the velocity rises from 10 m s^{-1} to 30 m s^{-1} in 8 s.
- $a = (30 - 10)/8 = 20/8 = 2.5 \text{ m s}^{-2}$
- $F = ma = 10 \times 2.5 = 25 \text{ N}$

Force = 25 N, in the direction of motion

Q12**3 Marks**

A bullet of mass 50 g moving at 100 m s^{-1} stops after penetrating 50 cm into a wooden block. Estimate the stopping force.

SOLUTION

- $m = 50 \text{ g} = 0.05 \text{ kg}$; $u = 100 \text{ m s}^{-1}$; $v = 0$; $s = 50 \text{ cm} = 0.5 \text{ m}$
- Using $v^2 = u^2 + 2as \rightarrow 0 = 100^2 + 2a(0.5)$
- $0 = 10000 + a \rightarrow a = -10,000 \text{ m s}^{-2}$
- $F = ma = 0.05 \times (-10,000) = -500 \text{ N}$

Stopping force = 500 N, acting opposite to the motion of the bullet

Q13**3 Marks**

A footballer kicks a 0.4 kg ball to a speed of 108 km h^{-1} with an estimated force of 800 N. Find the time of contact.

SOLUTION

- $v = 108 \text{ km h}^{-1} = 108 \times 5/18 = 30 \text{ m s}^{-1}$; $u = 0$; $m = 0.4 \text{ kg}$; $F = 800 \text{ N}$
- From $F = m(v - u)/t \rightarrow t = m(v - u)/F$
- $t = 0.4 \times 30 \div 800 = 12/800$

Time of contact = 0.015 s

Q14**3 Marks**

A 2 kg object moving at 10 m s^{-1} meets friction of 7 N and an additional opposing force of 3 N. How far does it travel before stopping?

SOLUTION

- Both forces oppose the motion, so they add: total opposing force = $7 + 3 = 10 \text{ N}$
- $a = F/m = -10/2 = -5 \text{ m s}^{-2}$
- Using $v^2 = u^2 + 2as$ with $u = 10$, $v = 0$:
 $0 = 100 + 2(-5)s \rightarrow 10s = 100 \rightarrow s = 10 \text{ m}$

The object travels 10 m before coming to rest

Q15

4 Marks

A tractor pulling mass m_1 with force F gives acceleration a_1 ; pulling m_2 with the same F gives a_2 . Find the acceleration when it pulls both together with force F .

SOLUTION

- For the harrow alone: $F = m_1 a_1 \rightarrow m_1 = F/a_1$
- For the trolley alone: $F = m_2 a_2 \rightarrow m_2 = F/a_2$
- Combined system: total mass $= m_1 + m_2 = F/a_1 + F/a_2 = F(a_1 + a_2)/(a_1 a_2)$
- New acceleration $a = F \div (m_1 + m_2) = F \div [F(a_1 + a_2)/(a_1 a_2)]$

$$a = a_1 a_2 / (a_1 + a_2)$$

Sanity check: the combined mass is larger than either alone, so a must be smaller than both a_1 and a_2 — and the formula does give that.

Q16

3 Marks

A bar magnet and a compass needle exert equal and opposite forces on each other, yet only the needle moves. Explain.

SOLUTION

- Newton's third law is not violated — the two magnetic forces **are** equal in magnitude and opposite in direction.
- But the **effect** of a force is an acceleration, and $a = F/m$.
- The compass needle is extremely light and is delicately balanced on a low-friction pivot, so even a small force produces a large, visible turning.
- The bar magnet is far more massive and rests on a surface where friction opposes any movement, so the same force produces an acceleration too small to notice.
- Equal forces therefore give very unequal accelerations. If the bar magnet were also suspended freely and were light, it would be seen to turn as well.

PART C — EXTRA QUESTIONS (SOLVED)

E1

1 Mark

The SI unit of force is

(i) joule (ii) newton (iii) watt (iv) pascal

(ii) newton

E2**1 Mark**

The measure of inertia of a body is its

(i) velocity (ii) acceleration (iii) mass (iv) weight

(iii) mass

E3**1 Mark**

Action and reaction forces

(i) act on the same body (ii) cancel each other (iii) act on two different bodies (iv) are unequal in magnitude

(iii) act on two different bodies

E4**1 Mark**

Assertion (A): It is easier to pull a roller than to push it.

Reason (R): Pulling reduces the force pressing the roller against the ground, thereby reducing friction.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5**2 Marks**

Why do passengers fall forward when a moving bus brakes suddenly?

SOLUTION

- The brakes stop the lower part of the body, which is in contact with the bus.
- The upper body, because of its **inertia of motion**, tends to continue moving forward at the earlier speed, so the passenger lurches forward.

E6**2 Marks**

Why is it difficult to walk on a smooth, wet marble floor?

SOLUTION

- Walking depends on friction: the foot pushes the ground backward and the ground pushes the foot forward.
- A smooth wet floor offers very little friction, so the backward push cannot be gripped and the foot slips instead of driving the body forward.

E7

2 Marks

State two situations where friction is useful and two where it is harmful.

SOLUTION

- **Useful:** it lets us walk without slipping; it lets vehicle brakes stop a car; it holds a nail in wood; it allows a pencil to mark paper.
- **Harmful:** it wears out machine parts and tyres; it wastes energy as heat in engines; it slows down moving vehicles, increasing fuel use.

E8

3 Marks

A force of 5 N acts on a body of mass 2 kg initially at rest. Find (i) the acceleration, (ii) the velocity after 4 s, (iii) the distance travelled in 4 s.

SOLUTION

- (i) $a = F/m = 5/2 = 2.5 \text{ m s}^{-2}$
- (ii) $v = u + at = 0 + 2.5 \times 4 = 10 \text{ m s}^{-1}$
- (iii) $s = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2} \times 2.5 \times 16 = 20 \text{ m}$

E9

3 Marks

Two blocks of masses 4 kg and 6 kg are tied by a light string on a frictionless surface and pulled by a horizontal force of 20 N applied to the 4 kg block. Find (i) the acceleration of the system and (ii) the tension in the string.

SOLUTION

- (i) **System:** total mass = 4 + 6 = 10 kg; only external force = 20 N
 $a = F/(m_1 + m_2) = 20/10 = 2 \text{ m s}^{-2}$
- (ii) **Tension:** consider the 6 kg block alone. The only horizontal force on it is the tension T.
 $T = m \times a = 6 \times 2 = 12 \text{ N}$
- **Check** with the 4 kg block: $20 - T = 4 \times 2 = 8 \rightarrow T = 12 \text{ N} \checkmark$

$$a = 2 \text{ m s}^{-2}; T = 12 \text{ N}$$

E10**3 Marks**

A cricketer moves his hands backward while catching a fast ball. Explain using Newton's second law, and name two other applications of the same principle.

SOLUTION

- The ball must be brought to rest, so the change in velocity is fixed.
- From $F = m(v - u)/t$, the force depends inversely on the stopping time t .
- By drawing his hands back, the cricketer increases t , so the force on his palms becomes much smaller and injury is avoided.
- **Other applications:** air bags and crumple zones in cars; a high-jump landing mat; packaging fragile goods in foam; a gymnast bending the knees on landing.

E11**4 Marks**

Case study: A rocket of mass 5000 kg ejects hot gases downward. (i) Which law explains its upward motion? (ii) If the gases exert an upward thrust of 75,000 N and the downward weight of the rocket is 50,000 N, find the net force and the acceleration. (iii) What happens to the acceleration as fuel is used up?

SOLUTION

- **(i) Newton's third law.** The rocket pushes the hot gases downward (action); the gases push the rocket upward with an equal and opposite force (reaction).
- **(ii) Net upward force = 75,000 – 50,000 = 25,000 N**
 $a = F/m = 25,000 / 5000 = 5 \text{ m s}^{-2}$ upward
- **(iii) As fuel burns, the mass of the rocket decreases.** For the same thrust, $a = F/m$ therefore **increases** — the rocket accelerates faster and faster as it rises.

State Newton's three laws of motion and give one everyday example of each.

SOLUTION

- **First law (law of inertia):** an object remains at rest, or continues in uniform motion in a straight line, unless acted upon by a net external force.
Example: dust flies out of a carpet when it is beaten — the carpet moves, the dust stays behind through inertia of rest.
- **Second law:** the acceleration produced is directly proportional to the net force and inversely proportional to the mass, and is in the direction of the force; $F = ma$.
Example: a loaded truck needs a much larger braking force than an empty one to stop in the same distance.
- **Third law:** for every action there is an equal and opposite reaction, the two acting on different bodies.
Example: a swimmer pushes the water backward and is pushed forward by the water.
- **Link between them:** the first law defines when a force is acting, the second measures it, and the third tells us that forces always occur in pairs.

CHAPTER 7

Work, Energy, and Simple Machines

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit III — Motion, Force, Work and Sound (23 marks)**. This chapter is numerically rich and the formulas are few, so it is among the easiest places in the paper to secure full marks. Energy-transformation questions and the KE/PE conversion of a falling or rising body appear almost every year.

7.1 Work done by a constant force

$$W = F \times s \quad (\text{displacement measured in the direction of the force})$$

- SI unit: **joule (J)**. $1 \text{ J} = 1 \text{ N} \times 1 \text{ m}$.
- **1 joule** is the work done when a force of 1 N displaces a body by 1 m in the direction of the force.
- Work is a **scalar**, but it can be positive, negative or zero.

Sign of work	When	Example
Positive	Force and displacement in the same direction	Lifting a bucket upward; a falling stone acted on by gravity
Negative	Force and displacement in opposite directions	Friction on a sliding box; gravity on a ball thrown upward
Zero	No displacement, or force perpendicular to displacement	Pushing a wall that does not move; a coolie walking on level ground with a load on his head

Scientific meaning of work is narrower than the everyday one. A student reading for six hours does no work in the physics sense; a man pushing a stalled car that does not budge does no work either.

7.2–7.4 Energy

Energy is the capacity to do work; its SI unit is also the **joule**. 1 kilowatt-hour (kWh) = 3.6×10^6 J.

Work–energy theorem: $W = \Delta E$ — the work done on a body equals the change in its energy

Kinetic energy: $KE = \frac{1}{2}mv^2$

Potential energy (near the Earth's surface): $PE = mgh$

Mechanical energy = $KE + PE$ — conserved when only gravity acts

- KE depends on the **square** of velocity — doubling the speed makes the kinetic energy four times greater. This is why stopping distance grows so steeply with speed.
- PE depends only on the **vertical height** gained, not on the path taken. Climbing stairs or riding a lift to the same floor gives the same gain in PE.
- **Law of conservation of energy:** energy can neither be created nor destroyed; it can only be transformed from one form to another. The total energy of an isolated system remains constant.
- For a freely falling body, PE steadily converts to KE, and at every point $PE + KE = mgh$ (the original value).

Common energy transformations

Situation	Transformation
Truck moving uphill	Chemical (fuel) → kinetic + potential (+ heat)
Unwinding of a watch spring	Elastic potential → kinetic
Photosynthesis	Light (solar) → chemical
Water flowing from a dam	Potential → kinetic (→ electrical in a turbine)
Burning matchstick	Chemical → heat + light
Firecracker exploding	Chemical → heat + light + sound + kinetic
Speaking into a microphone	Sound → electrical
Glowing electric bulb	Electrical → light + heat
Solar panel	Light (solar) → electrical

7.5 Power

$$\text{Power} = \text{Work done} \div \text{time taken} \quad \bullet \quad P = W/t$$

- SI unit: **watt (W)**. $1 \text{ W} = 1 \text{ J s}^{-1}$. $1 \text{ kW} = 1000 \text{ W}$.
- Power is the **rate** of doing work. Two people carrying the same load up the same stairs do equal work, but the faster one has greater power.
- Doubling the speed of a task halves the time and therefore **doubles** the power required for the same work.

7.6 Simple machines

A **simple machine** changes the magnitude or the direction of the applied force to make work easier. It **does not reduce the total work done** and never creates energy.

$$\text{Mechanical advantage (MA)} = \text{Load} \div \text{Effort} \quad \bullet \quad \text{For a lever: Load} \times \text{load arm} = \text{Effort} \times \text{effort arm}$$

Class of lever	Arrangement	Examples
First class	Fulcrum in between effort and load	Scissors, crowbar, pliers, seesaw, balance scale, a claw hammer pulling a nail
Second class	Load in between fulcrum and effort	Wheelbarrow, bottle opener, lemon squeezer, nutcracker
Third class	Effort in between fulcrum and load	Tongs, tweezers, broom, fishing rod, hammer, oar, human forearm

The three classes of lever — what lies in the middle decides the class

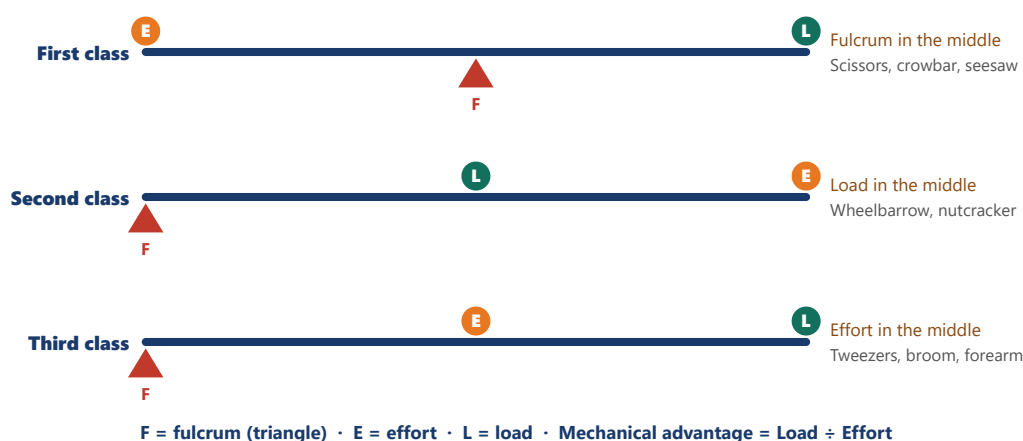


Fig. 7.B — First, second and third class levers

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Why perpetual motion machines fail: every real machine loses some energy to friction, air resistance and sound. The useful output is therefore always less than the input, so the machine gradually slows and stops. No arrangement of wheels, weights or magnets can create energy.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

2 Marks

State whether True or False.

SOLUTION

- (i) **False** — work is done only if the object is displaced; force alone is not enough.
- (ii) **True** — the force and the displacement are both upward, so the work is positive.
- (iii) **True** — both work and energy are measured in joules.
- (iv) **False** — a motionless stretched rubber band has **elastic potential** energy, not kinetic energy.
- (v) **True** — this is the law of conservation of energy.

Q2

2 Marks

Fill in the blanks.

SOLUTION

- (i) Work done = **Force** × **Displacement** (in the direction of force)
- (ii) 1 joule of work is done when a force of **1** newton displaces an object by 1 metre in the direction of the force
- (iii) Kinetic energy = $\frac{1}{2}mv^2$
- (iv) Potential energy at a small height h = **mgh**
- (v) Power is defined as the **rate** at which work is done

Q3

2 Marks

When a ball thrown upwards reaches its highest point, which statement(s) are correct?

(iii) Its kinetic energy is zero and (iv) Its potential energy is maximum

WHY THE OTHERS ARE WRONG

- (i) The force of gravity continues to act on the ball at every instant, so it is not zero.
- (ii) Since gravity acts, the acceleration is still $g = 9.8 \text{ m s}^{-2}$ downward, not zero.
- At the top the velocity is momentarily zero, so $KE = \frac{1}{2}mv^2 = 0$, and all the energy has become potential energy — hence PE is maximum.

Q4

5 Marks

Identify the energy transformation in each situation.

SOLUTION

Situation	Energy transformation
(i) A truck moving uphill	Chemical energy of fuel → kinetic energy + potential energy (and heat)
(ii) Unwinding of a watch spring	Elastic potential energy → kinetic energy
(iii) Photosynthesis in green leaves	Light (solar) energy → chemical energy stored in glucose
(iv) Water flowing from a dam	Potential energy → kinetic energy
(v) Burning of a matchstick	Chemical energy → heat and light energy
(vi) Explosion of a firecracker	Chemical energy → heat, light, sound and kinetic energy
(vii) Speaking into a microphone	Sound energy → electrical energy
(viii) A glowing electric bulb	Electrical energy → light and heat energy
(ix) A solar panel	Light (solar) energy → electrical energy

Q5

3 Marks

A 50 kg student rises 72.5 m, once by lift and once by stairs; $g = 10 \text{ m s}^{-2}$. (i) PE gained by lift, (ii) PE gained by stairs, (iii) what do you conclude?

SOLUTION

- (i) $PE = mgh = 50 \times 10 \times 72.5 = \mathbf{36,250 \text{ J}}$
- (ii) The vertical height gained is exactly the same, so $PE = 50 \times 10 \times 72.5 = \mathbf{36,250 \text{ J}}$
- (iii) Gravitational potential energy depends **only on the vertical height** gained, and not at all on the path followed. Gravity is therefore a conservative force, and the work done against it between two points is path-independent.

Q6

3 Marks

A crane lifts mass m to the 10th floor in time t , then the same mass to the 20th floor in time $2t$. How much more energy and power are required?

SOLUTION

- Let the height of each floor be h , so the first lift is through $10h$ and the second through $20h$.

- Energy:** $E_1 = mg(10h)$; $E_2 = mg(20h) = 2 \times E_1$

The second lift needs **twice the energy** of the first.

- Power:** $P_1 = E_1/t$; $P_2 = E_2/2t = 2E_1/2t = E_1/t = P_1$

The power required is **exactly the same**.

- Doubling both the work and the time leaves the rate of doing work unchanged.

Energy required is twice as much; power required is unchanged

Q7

3 Marks

Which factors determine the energy required to raise a flag to the top of a flagpole? Does raising it slowly or quickly change the work done? If the speed is doubled, how does the power change?

SOLUTION

- Factors determining the energy:** the **mass** of the flag (and rope), the **height** of the flagpole, and the **acceleration due to gravity** — since $W = mgh$. Friction in the pulley adds a small extra amount.
- Slow or fast makes no difference to the work done.** The work equals mgh , which depends only on mass and height, not on the time taken.
- If the speed is doubled:** the same work is done in half the time. Since $P = W/t$, halving t **doubles the power** required.
- This is why hoisting a flag quickly feels much harder even though the total effort is the same.

Q8

3 Marks

A 60 kg man on a 100 kg scooter accelerates to velocity v . The next day his 40 kg son joins him and the same speed is reached in the same time. Find the ratio of fuel used on the two days.

SOLUTION

- All the fuel energy goes into the kinetic energy of the moving system.
- Day 1:** total mass = $100 + 60 = 160$ kg $\rightarrow E_1 = \frac{1}{2} \times 160 \times v^2 = 80v^2$
- Day 2:** total mass = $100 + 60 + 40 = 200$ kg $\rightarrow E_2 = \frac{1}{2} \times 200 \times v^2 = 100v^2$
- Ratio $E_1 : E_2 = 80 : 100 = 4 : 5$

Fuel used on the two days is in the ratio 4 : 5

A child and an adult balance on a seesaw with sliding seats; the adult weighs twice the child. Draw a figure showing their distances from the fulcrum.

SOLUTION

- A seesaw is a **first-class lever**; it balances when
 $(\text{weight of child}) \times (\text{distance of child}) = (\text{weight of adult}) \times (\text{distance of adult})$
- Let the child's weight be W and the adult's be $2W$, with the child at distance d_c and the adult at d_a .
- $W \times d_c = 2W \times d_a \rightarrow d_c = 2d_a$
- So the **child must sit twice as far from the fulcrum as the adult**. If the adult sits 1 m from the fulcrum, the child sits 2 m on the other side.

A seesaw is a first-class lever — the fulcrum lies between the two loads

It balances when $W \times 2d = 2W \times d$

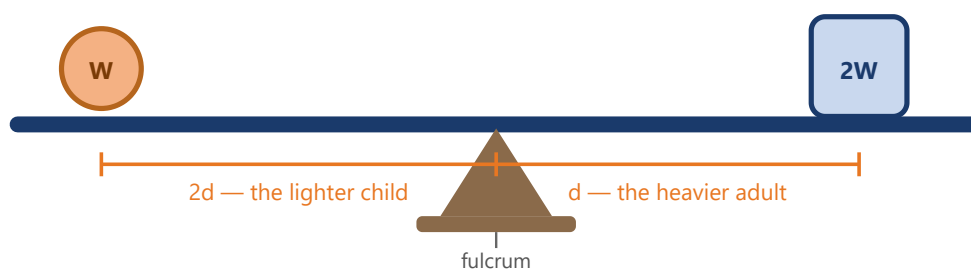


Fig. 7.A — The lighter child must sit at twice the distance from the fulcrum

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook
 Exploration — Textbook of Science for Grade 9.

Q10

3 Marks

A 2 kg ball is thrown up at 20 m s^{-1} . (i) Sign of work done by gravity going up and coming down. (ii) If it reaches 19.4 m, how much work was done by air resistance? ($g = 10 \text{ m s}^{-2}$)

(I) SOLUTION

- **Upward motion:** gravity acts downward while the displacement is upward, so the work done by gravity is **negative**.
- **Downward motion:** gravity and displacement are both downward, so the work done by gravity is **positive**.

(II) SOLUTION

- Initial kinetic energy $= \frac{1}{2}mv^2 = \frac{1}{2} \times 2 \times 20^2 = 400 \text{ J}$
- At the highest point, $KE = 0$, and $PE \text{ gained} = mgh = 2 \times 10 \times 19.4 = 388 \text{ J}$
- Without air resistance the ball would have converted all 400 J into PE; it converted only 388 J.
- Work done by air resistance $= 388 - 400 = -12 \text{ J}$

(i) Negative going up, positive coming down (ii) -12 J

Q11

4 Marks

A 10.0 kg block has 180 J of kinetic energy at 0 m; a variable force acts on it up to 4 m (Fig. 7.37). Find its speed at (i) 0 m and (ii) 4 m. Does it ever have negative acceleration?

SOLUTION

- (i) $KE = \frac{1}{2}mv^2 \rightarrow 180 = \frac{1}{2} \times 10 \times v^2 \rightarrow v^2 = 36 \rightarrow v = 6 \text{ m s}^{-1}$
- **Work done by the force** = area under the force–displacement graph. From the graph the force is 50 N over the first 3 m and zero thereafter:
 $W = 50 \times 3 = 150 \text{ J}$
- (ii) By the work–energy theorem, $KE \text{ at } 4 \text{ m} = 180 + 150 = 330 \text{ J}$
 $330 = \frac{1}{2} \times 10 \times v^2 \rightarrow v^2 = 66 \rightarrow v = \sqrt{66} \approx 8.12 \text{ m s}^{-1}$
- **Negative acceleration? No.** The force is either positive (along the motion) or zero throughout, and friction is negligible; so the block never decelerates.

Q12

3 Marks

Gravity on the Moon is about $1/6$ of that on Earth. An astronaut can throw a ball 8 m high on Earth. How high will it go on the Moon with the same initial velocity?

SOLUTION

- At the top the whole kinetic energy has become potential energy: $\frac{1}{2}mu^2 = mgh \rightarrow h = u^2/2g$
- Since u is the same, h is **inversely proportional to g** .
- $g_{\text{Moon}} = g_{\text{Earth}}/6$, so $h_{\text{Moon}} = 6 \times h_{\text{Earth}}$
- $h_{\text{Moon}} = 6 \times 8 = 48 \text{ m}$

The ball will rise 48 m on the Moon

Q13

4 Marks

A 1000 kg car brakes to a stop; speed–time graph Fig. 7.38 with A, B, C. (i) Describe the motion from A to B. (ii) KE at A. (iii) Work done by brakes from B to C. (iv) What does the kinetic energy transform into?

SOLUTION

- (i) Between A and B the graph is a horizontal line, so the car moves with **constant speed of 35 m s^{-1}** . This is the driver's reaction time, before the brakes are applied.
- (ii) KE at A = $\frac{1}{2}mv^2 = \frac{1}{2} \times 1000 \times 35^2 = \frac{1}{2} \times 1000 \times 1225 = \mathbf{612,500 \text{ J}}$
- (iii) From B to C the car comes to rest, so its final KE is zero.
Work done by the brakes = change in KE = $0 - 612,500 = \mathbf{-612,500 \text{ J}}$
The minus sign shows the braking force opposes the motion.
- (iv) The kinetic energy is transformed mainly into **heat (thermal energy)** in the brake pads, discs, tyres and road surface, with a small part appearing as **sound**. No energy is destroyed — it is only converted, in agreement with the law of conservation of energy.

Q14

4 Marks

A 0.5 kg ball on a frictionless track has PE = 30 J and velocity 0 at O (Fig. 7.39). Find its velocity at P, Q and R.

METHOD

- The track is frictionless, so **mechanical energy is conserved**: KE + PE = 30 J everywhere.
- At any point, KE = 30 – PE, and $v = \sqrt{2 \text{ KE} / m} = \sqrt{4 \text{ KE}}$ since $m = 0.5 \text{ kg}$.

CALCULATIONS

- At P** (PE = 20 J): KE = 30 – 20 = 10 J
 $10 = \frac{1}{2} \times 0.5 \times v^2 \rightarrow v^2 = 40 \rightarrow v = 2\sqrt{10} \approx 6.32 \text{ m s}^{-1}$
- At Q** (PE = 30 J): KE = 30 – 30 = 0
 $v = 0 \text{ m s}^{-1}$ — the ball is momentarily at rest here
- At R** (PE = 40 J): this would require KE = 30 – 40 = –10 J, which is impossible.
 Therefore **the ball can never reach R**; it turns back at Q.

Q15

4 Marks

A 1.5 kg coconut falls from a height of 10 m onto wet sand. (i) Find the velocity just before impact. (ii) If the average resistive force of sand is 3000 N, find the depth of the depression. ($g = 10 \text{ m s}^{-2}$)

(I) SOLUTION

- Using $v^2 = u^2 + 2gh$ with $u = 0$:
 $v^2 = 2 \times 10 \times 10 = 200$
- $v = \sqrt{200} = 10\sqrt{2} \approx 14.14 \text{ m s}^{-1}$, directed downward

(II) SOLUTION

- Energy of the coconut on reaching the sand = $mgh = 1.5 \times 10 \times 10 = 150 \text{ J}$
 (equivalently KE = $\frac{1}{2} \times 1.5 \times 200 = 150 \text{ J}$ — the same value)
- All of this is used up doing work against the sand: $W = F \times d$
- $150 = 3000 \times d \rightarrow d = 150/3000 = 0.05 \text{ m}$

(i) $10\sqrt{2} \approx 14.14 \text{ m s}^{-1}$ (ii) depth = 0.05 m = 5 cm

PART C — EXTRA QUESTIONS (SOLVED)

E1

1 Mark

A coolie carrying a load on his head walks horizontally on a level platform. The work done by him against gravity is
 (i) maximum (ii) mgh (iii) zero (iv) negative

(iii) zero

E2**1 Mark**

If the velocity of a body is doubled, its kinetic energy becomes

(i) double (ii) half (iii) four times (iv) unchanged

(iii) four times

E3**1 Mark**

A wheelbarrow is an example of a

(i) first-class lever (ii) second-class lever (iii) third-class lever (iv) pulley

(ii) second-class lever

E4**1 Mark**

Assertion (A): A simple machine does not reduce the total work to be done.

Reason (R): A machine only changes the magnitude or direction of the applied force.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5**2 Marks**

Define 1 watt of power. How many joules are there in 1 kWh?

SOLUTION

- **1 watt** is the power of an agent that does 1 joule of work in 1 second.
- $1 \text{ kWh} = 1000 \text{ W} \times 3600 \text{ s} = 3.6 \times 10^6 \text{ J}$

E6**2 Marks**

A force of 20 N displaces a body by 5 m in the direction of the force. Calculate the work done. If the same force acts perpendicular to the displacement, what is the work done?

SOLUTION

- $W = F \times s = 20 \times 5 = \mathbf{100 \text{ J}}$
- If the force is perpendicular to the displacement, there is no displacement in the direction of the force, so **W = 0**.

E7**3 Marks**

A boy of mass 40 kg climbs a staircase of 20 steps, each 0.2 m high, in 10 s. Find the work done and his power. ($g = 10 \text{ m s}^{-2}$)

SOLUTION

- Total height $h = 20 \times 0.2 = 4 \text{ m}$
- $W = mgh = 40 \times 10 \times 4 = 1600 \text{ J}$
- $P = W/t = 1600/10 = 160 \text{ W}$

Work = 1600 J; Power = 160 W

E8**3 Marks**

An object of mass 5 kg falls freely from a height of 20 m. Find its potential energy at the top, its kinetic energy just before hitting the ground, and its velocity at that moment. ($g = 10 \text{ m s}^{-2}$)

SOLUTION

- PE at the top $= mgh = 5 \times 10 \times 20 = \mathbf{1000 \text{ J}}$
- Just before impact all of it has become kinetic energy, so KE = **1000 J**
- $1000 = \frac{1}{2} \times 5 \times v^2 \rightarrow v^2 = 400 \rightarrow v = \mathbf{20 \text{ m s}^{-1}}$

E9**3 Marks**

A crowbar 1.5 m long is used to lift a stone of weight 900 N. The fulcrum is placed 0.3 m from the stone. Find the effort required and the mechanical advantage.

SOLUTION

- Load arm = 0.3 m; effort arm = $1.5 - 0.3 = 1.2 \text{ m}$
- Load $\times$ load arm = Effort $\times$ effort arm
 $900 \times 0.3 = E \times 1.2$
- $E = 270/1.2 = \mathbf{225 \text{ N}}$
- MA = Load/Effort = $900/225 = \mathbf{4}$ (equivalently, effort arm $\div$ load arm = $1.2/0.3 = 4$)

E10**3 Marks**

Explain why the total energy of a freely falling body remains constant throughout its fall.

SOLUTION

- At the top the body is at rest at height h : $KE = 0$, $PE = mgh$, total = mgh .
- After falling a distance x , its speed satisfies $v^2 = 2gx$, so $KE = \frac{1}{2}m(2gx) = mgx$, while $PE = mg(h - x)$. Total = $mgx + mgh - mgx = mgh$.
- Just before hitting the ground, $h = 0$ so $PE = 0$, and $v^2 = 2gh$ gives $KE = mgh$. Total = mgh again.
- At every stage the sum $KE + PE = mgh$ — potential energy is steadily converted into kinetic energy, and the total mechanical energy stays constant, as required by the law of conservation of energy (air resistance being neglected).

E11**4 Marks**

Case study: A hydroelectric plant uses water stored 60 m above the turbine. 500 kg of water falls each second. Taking $g = 10 \text{ m s}^{-2}$, (i) find the potential energy released per second, (ii) the theoretical power output, (iii) if the plant is 80% efficient, find the actual electrical power, and (iv) name the energy conversions involved.

SOLUTION

- (i) PE per second = $mgh = 500 \times 10 \times 60 = \mathbf{300,000 \text{ J}}$
- (ii) Theoretical power = energy per second = $\mathbf{300,000 \text{ W} = 300 \text{ kW}}$
- (iii) Actual power = 80% of 300 kW = $0.8 \times 300 = \mathbf{240 \text{ kW}}$
- (iv) Potential energy of stored water $\rightarrow$ kinetic energy of falling water $\rightarrow$ mechanical (rotational) energy of the turbine $\rightarrow$ electrical energy in the generator. The missing 20% appears as heat, sound and friction losses.

E12**5 Marks**

Show that the kinetic energy of a body of mass m moving with velocity v is $\frac{1}{2}mv^2$.

DERIVATION

- Let a body of mass m , initially at rest, be acted on by a constant force F , which gives it acceleration a and a velocity v after travelling a distance s .
- Work done by the force, $W = F \times s$
- From Newton's second law, $F = ma$, so $W = mas$
- From the third equation of motion with $u = 0$: $v^2 = 0 + 2as \rightarrow s = v^2/2a$
- Substituting: $W = ma \times v^2/2a = \frac{1}{2}mv^2$
- By the work-energy theorem this work is stored in the body as its energy of motion.

$$\text{Kinetic energy} = \frac{1}{2}mv^2$$

CHAPTER 8

Journey Inside the Atom

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES



Weightage

Part of **Unit II — Matter, Its Nature and Behaviour (25 marks)**, with Chapters 5 and 9. Electronic configuration, valency, and isotope/isobar identification are almost guaranteed questions; the gold-foil experiment is the standard 3-mark long answer.



8.1–8.2 Evolution of atomic models

Scientist	Model	Why it was replaced
Dalton (1808)	Atoms are tiny, indivisible, indestructible particles; atoms of an element are identical	Discovery of electrons, protons and neutrons showed the atom is divisible; isotopes showed atoms of one element can differ
J. J. Thomson (1897)	"Plum pudding" — electrons embedded in a sphere of positive charge, like seeds in a watermelon	Could not explain why some α -particles were deflected through large angles
Rutherford (1911)	A tiny, dense, positively charged nucleus at the centre; electrons revolve around it; most of the atom is empty space	Could not explain the stability of the atom — a revolving charged electron should continuously radiate energy, spiral in, and collapse into the nucleus
Niels Bohr (1913)	Electrons revolve only in certain fixed orbits (shells) of definite energy, and do not radiate energy while in them	Successfully explained stability and the spectra of simple atoms; refined later by quantum mechanics
Chadwick (1932)	Discovered the neutron — a neutral particle in the nucleus	Completed the picture of the three subatomic particles

Rutherford's gold-foil (α -scattering) experiment

- **Set-up:** a beam of fast-moving, positively charged α -particles was directed at a very thin gold foil, surrounded by a fluorescent screen.
- **Observation 1:** most α -particles passed straight through → **most of the atom is empty space.**
- **Observation 2:** a small fraction were deflected through small angles → there is a **positive charge** concentrated somewhere inside.
- **Observation 3:** about 1 in 12,000 bounced straight back → the positive charge and nearly all the **mass** are packed into an extremely small volume — the **nucleus**.
- **Conclusion:** the nucleus is positively charged, extremely dense, and about 10^5 times smaller than the atom.

 **No MLI diagram here — use the NCERT figure**

Rutherford's gold-foil (α -scattering) apparatus

The whole point of this figure is the *proportion* — almost every α -particle going straight through, a very few deflected, about one in twelve thousand bouncing back. Any hand-made sketch exaggerates the deflected paths and teaches the wrong impression, so we describe it in words above and leave the drawing to NCERT.

When you open the NCERT figure, make sure you can name:

- The α -particle source and the narrow beam
- The very thin gold foil
- The circular fluorescent (zinc sulphide) screen around it
- Most particles passing straight through — the atom is mostly empty space
- A few deflected through small angles — a concentrated positive charge
- About 1 in 12,000 rebounding — a tiny, dense, massive nucleus

Where to look: the α -scattering figure in Chapter 8, *Journey Inside the Atom*.

8.3 Subatomic particles

Particle	Symbol	Charge	Relative mass	Location	Discovered by
Electron	e^-	-1	1/1840 u (negligible)	Shells outside the nucleus	J. J. Thomson
Proton	p^+	+1	1 u	Nucleus	E. Goldstein / Rutherford
Neutron	n	0	1 u	Nucleus	James Chadwick

Electrons are held in the atom by the **electrostatic force of attraction** between the negatively charged electron and the positively charged nucleus. This attraction supplies exactly the inward force needed to keep the electron in its orbit.

8.4–8.6 Symbols, atomic number, mass number

Atomic number Z = number of protons = number of electrons (in a neutral atom)

Mass number A = number of protons + number of neutrons = number of nucleons

Number of neutrons = $A - Z$

The symbol is written as A_ZX , for example ${}^{23}_{11}\text{Na}$. The atomic number alone fixes the identity of the element.

Term	Same	Different	Example
Isotopes	Atomic number (same element)	Mass number (different neutrons)	${}^{35}\text{Cl}$ and ${}^{37}\text{Cl}$; ${}^1\text{H}$, ${}^2\text{H}$, ${}^3\text{H}$
Isobars	Mass number	Atomic number (different elements)	${}^{40}_{18}\text{Ar}$ and ${}^{40}_{20}\text{Ca}$

Uses of isotopes: U-235 as nuclear fuel; Co-60 in cancer treatment; I-131 in treating goitre and thyroid disorders; C-14 in carbon dating.

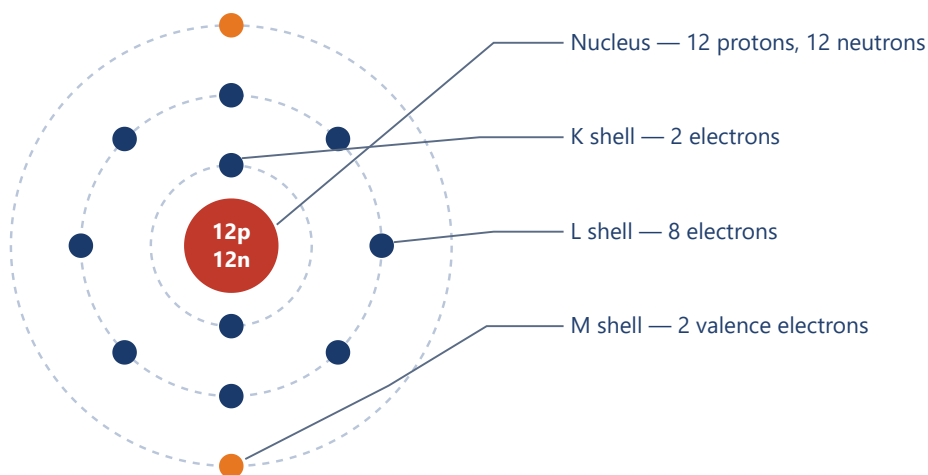
Average atomic mass = Σ (fractional abundance $\times$ mass of each isotope)

8.7–8.8 Electron distribution and valency

- Shells are named **K, L, M, N ...** outward from the nucleus.
- **Bohr–Bury rule:** the maximum number of electrons a shell can hold is $2n^2$ — K = 2, L = 8, M = 18, N = 32.
- The **outermost shell** can never hold more than **8** electrons, and shells are filled in order.
- **Valence electrons** = electrons in the outermost shell.
- **Valency** = the combining capacity of an atom = number of electrons gained, lost or shared to reach a stable octet (or duplet for the K shell).

Valence electrons	1	2	3	4	5	6	7	8
Valency	1	2	3	4	3	2	1	0

Rule: if the outermost shell has 1–4 electrons, valency = that number; if it has 5–7, valency = 8 – that number. A complete octet (or 2 for helium) gives valency 0 — the noble gases are stable and unreactive.



$Z = 12, A = 24$ · configuration 2, 8, 2 · valency 2

Fig. 8.A — Arrangement of electrons in a magnesium atom ($Z = 12, A = 24$)

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

3 Marks

Choose the correct options about Rutherford's gold foil experiment and explain the reason for correct and incorrect options.

(ii) and (iii) are correct

EXPLANATION

- **(ii) Correct.** The plum-pudding model predicted that all α -particles would pass through with only tiny deflections, since the positive charge was thought to be spread out. The observation of large deflections disproved it and led to the idea of a compact central nucleus.
- **(iii) Correct.** Only a very heavy, highly concentrated positive charge could turn back a fast, heavy α -particle — showing that the mass and positive charge are packed into a tiny centre.
- **(i) Incorrect.** The neutron is uncharged and was discovered much later, by Chadwick in 1932. α -scattering gives no information about it.
- **(iv) Incorrect.** Electrons are far too light to deflect an α -particle appreciably; the experiment revealed nothing about how electrons move. Their orbital arrangement was proposed by Rutherford and refined by Bohr on other grounds.

Q2

4 Marks

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

SOLUTION

- **(i) Incorrect.** Bohr's key postulate is precisely the opposite — while an electron stays in a permitted orbit it does **not** radiate energy, which is why the atom is stable and the electron does not spiral into the nucleus.
- **(ii) Incorrect.** Electrons cannot exist anywhere at random; only certain orbits with definite, **quantised** energies are allowed.
- **(iii) Correct.** This is the central statement of the Bohr model — electrons revolve in orbits of fixed energy without losing energy.
- **(iv) Incorrect.** An electron is never found between two energy levels; it absorbs or emits a definite quantum of energy and **jumps** from one permitted orbit to another.

Q3

3 Marks

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.

WORKING

Species	Protons (Z)	Neutrons	Mass number (A)
X	18	19	37
Y	17	18	35
Z	17	20	37

ANSWERS

- **(i) Y and Z are isotopes.** Both have 17 protons, so both are atoms of the same element (chlorine), but their mass numbers are 35 and 37 because they have different numbers of neutrons.
- **(ii) Z and X are isobars.** Both have mass number 37, but their atomic numbers are 17 and 18, so they are atoms of **different** elements (chlorine and argon).

Q4

3 Marks

What conclusion did Rutherford draw about the position and characteristics of the atom's positively charged part, from the few α -particles that bounced back?

SOLUTION

- An α -particle is itself positive and fast-moving; only a strong repulsion from a large concentrated positive charge could turn it back.
- Since only about 1 in 12,000 particles bounced back, the region responsible must be **extremely small** compared with the atom.
- To reverse the motion of a heavy α -particle, that region must also be **very massive** — hence nearly the entire mass of the atom is concentrated there.
- **Conclusion:** at the **centre** of the atom lies a tiny, dense, positively charged **nucleus** containing almost all the atom's mass; the rest of the atom is largely empty space through which most α -particles pass undisturbed.

Q5

2 Marks

Arrange the statements in the correct chronological order to show how atomic models evolved.

CORRECT ORDER

- **1. (iv) Dalton** — atoms as indivisible particles (1808)
- **2. (ii) Thomson** — the plum-pudding model with electrons embedded in positive charge (1904)
- **3. (iii) Rutherford** — a dense central nucleus (1911)
- **4. (i) Bohr** — electrons in fixed orbits of definite energy (1913)

(iv) → (ii) → (iii) → (i)

Each model was not simply "wrong" — each explained the evidence available at the time and was revised when new evidence appeared. This is the self-correcting nature of science.

Q6

2 Marks

Electrons move around the nucleus in orbits. Why do they not fly away from the atom?

SOLUTION

- The nucleus is positively charged (protons) and the electron is negatively charged.
- Unlike charges attract, so a strong **electrostatic force of attraction** acts between them.
- This inward attraction continuously bends the electron's path into an orbit, exactly balancing its tendency to fly off in a straight line.
- To escape, an electron would have to be supplied with enough energy to overcome this attraction — which is what happens during ionisation.

Q7

1 Mark

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.

(ii) Both A and R are true, but R is not the correct explanation of A

EXPLANATION

- A is true — identifying electrons, protons and neutrons is exactly what made the modern picture of the atom possible.
- R is also true — a neutral atom has equal numbers of protons and electrons.
- But R only describes electrical neutrality; it does not explain *why* discovering the particles advanced our understanding of structure.

Q8

3 Marks

For a magnesium atom with mass number 24 and atomic number 12, determine (i) protons, (ii) neutrons, (iii) electrons, and illustrate the arrangement of electrons.

SOLUTION

- (i) **Protons** = atomic number = **12**
- (ii) **Neutrons** = $A - Z = 24 - 12 = 12$
- (iii) **Electrons** = protons (neutral atom) = **12**
- **Electronic configuration:** $K = 2, L = 8, M = 2 \rightarrow 2, 8, 2$
- Valence electrons = 2, so the valency of magnesium is 2 and it forms Mg^{2+} .
- The arrangement is shown in Fig. 8.A above — a nucleus of 12 protons and 12 neutrons with 2, 8 and 2 electrons in the K, L and M shells.

Q9

5 Marks

Find the required information for the elements shown in Fig. 8.17 (a), (b), (c) and (d).

SOLUTION

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

Note how valency is worked out: Li and Al have 1 and 3 valence electrons (fewer than 4), so valency equals that number. N and F have 5 and 7 (more than 4), so valency = $8 - 5 = 3$ and $8 - 7 = 1$.

Q10

3 Marks

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 succeeded?

SOLUTION

- **The problem with Rutherford's model:** an electron moving in a circular orbit is constantly accelerating (its direction changes continuously). According to classical electromagnetic theory, an accelerating charged particle must **radiate energy continuously**.
- Losing energy, the electron would spiral inward and collapse into the nucleus in a tiny fraction of a second. Matter would therefore be unstable — which contradicts the fact that atoms are stable.
- **Bohr's solution:** he postulated that only certain orbits, of fixed and definite energy, are permitted, and that while an electron revolves in such an orbit it does **not** radiate energy at all.
- Energy is emitted or absorbed only when an electron **jumps** from one permitted orbit to another, and then in fixed quanta.
- Since the electron in the lowest permitted orbit cannot fall any further, the atom is stable — and this also explained the sharp line spectra of elements, which Rutherford's model could not.

Q11

2 Marks

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

SOLUTION

- In a neutral atom, number of protons = number of electrons = 31, so $Z = 31$
- Mass number $A = 70$
- Neutrons = $A - Z = 70 - 31 = 39$

Number of neutrons = 39 (the element is gallium)

Q12

2 Marks

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

SOLUTION

- (i) Neutrons = $A - Z = 197 - 79 = 118$
- (ii) The atom is neutral, so electrons = protons = **79**
- The element with $Z = 79$ is **gold (Au)**.

Q13

4 Marks

Complete Table 8.5.

COMPLETED TABLE

Atomic number	Mass number	Neutrons	Protons	Electrons	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

The only two relations needed: $Z = \text{protons} = \text{electrons}$, and $A = \text{protons} + \text{neutrons}$.

Q14

5 Marks

Element X has mass number 35 and 18 neutrons. Answer (i) to (vii).

SOLUTION

- (i) Protons = $A - \text{neutrons} = 35 - 18 = 17$; electrons = **17**
- (ii) Atomic number = number of protons = **17**
- (iii) The element is **chlorine (Cl)**
- (iv) Electronic configuration: **2, 8, 7**
- (v) Valence electrons = **7** (so valency = $8 - 7 = 1$)
- (vi) Adding two neutrons keeps $Z = 17$ but raises A to $35 + 2 = 37$
- (vii) The new atom has the same atomic number but a different mass number, so the two are **isotopes** of chlorine (^{35}Cl and ^{37}Cl)

Q15

4 Marks

An atom has 12 protons and 12 neutrons. All electrons are replaced by hypothetical particles of the same charge but 500 times heavier. What is the effect on (i) atomic number, (ii) atomic mass, (iii) mass number, (iv) overall charge?

SOLUTION

- **(i) Atomic number — no change.** It is defined by the number of **protons** in the nucleus, which is still 12. The identity of the element (magnesium) is unchanged.
- **(ii) Atomic mass — it increases.** Ordinary electrons contribute almost nothing ($1/1840$ u each), but 12 particles that are 500 times heavier add roughly $12 \times 500/1840 \approx 3.3$ u, which is no longer negligible. So the actual mass of the atom rises noticeably.
- **(iii) Mass number — no change.** Mass number counts only **nucleons** — protons plus neutrons — which remain $12 + 12 = 24$.
- **(iv) Overall charge — no change; the atom remains neutral.** The replacement particles carry the same charge as electrons, so 12 negative charges still balance the 12 protons.

The point of this question is to separate three ideas that students often merge: **atomic number** (a count of protons), **mass number** (a count of nucleons) and **actual mass** (which includes every particle, electrons included).

PART C — EXTRA QUESTIONS (SOLVED)

E1

1 Mark

The maximum number of electrons that the M shell can hold is

(i) 8 (ii) 18 (iii) 32 (iv) 2

(ii) 18

E2

1 Mark

Isobars have the same

(i) number of protons (ii) number of neutrons (iii) mass number (iv) number of electrons

(iii) mass number

E3**1 Mark**

The isotope used in the treatment of cancer is

(i) U-235 (ii) Co-60 (iii) I-131 (iv) C-14

(ii) Co-60

E4**1 Mark**

Assertion (A): Noble gases are chemically unreactive.

Reason (R): Their outermost shells contain a complete octet of electrons (or a duplet in helium).

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5**2 Marks**

Write the electronic configuration and valency of sodium ($Z = 11$) and sulfur ($Z = 16$).

SOLUTION

- **Sodium:** 2, 8, 1 — 1 valence electron, so valency = **1** (loses one electron to form Na^+).
- **Sulfur:** 2, 8, 6 — 6 valence electrons, so valency = $8 - 6 = 2$ (gains two electrons to form S^{2-}).

E6**2 Marks**

Why is the mass of an atom concentrated almost entirely in its nucleus?

SOLUTION

- Protons and neutrons each have a relative mass of 1 u and both lie in the nucleus.
- An electron's mass is only about $1/1840$ u, so even in a heavy atom the electrons contribute a negligible fraction of the total mass.

E7**2 Marks**

Define isotopes and give two uses.

SOLUTION

- **Isotopes** are atoms of the same element having the same atomic number but different mass numbers (different numbers of neutrons).
- **Uses:** U-235 as fuel in nuclear reactors; I-131 in the treatment of thyroid disorders; C-14 in dating archaeological remains.

E8

3 Marks

Chlorine occurs as two isotopes, ^{35}Cl and ^{37}Cl , in the ratio 3 : 1. Calculate its average atomic mass.

SOLUTION

- Fractional abundance of $^{35}\text{Cl} = 3/4 = 0.75$; of $^{37}\text{Cl} = 1/4 = 0.25$
- Average atomic mass = $(35 \times 0.75) + (37 \times 0.25)$
- = $26.25 + 9.25 = 35.5 \text{ u}$

Average atomic mass of chlorine = 35.5 u

E9

3 Marks

State any three postulates of Bohr's model of the atom.

SOLUTION

- Electrons revolve around the nucleus only in certain permitted circular orbits or **shells**, each with a fixed, definite energy.
- While revolving in such an orbit, an electron **does not radiate energy**, so the atom remains stable.
- Energy is absorbed or emitted only when an electron **jumps** from one shell to another, and the amount is exactly the difference between the two energy levels.
- The shells are named K, L, M, N ... and can hold at most $2n^2$ electrons each.

E10

3 Marks

An element has the electronic configuration 2, 8, 8, 2. Find (i) its atomic number, (ii) its valency, (iii) whether it is a metal or a non-metal, with reason.

SOLUTION

- (i) Total electrons = $2 + 8 + 8 + 2 = 20$, so atomic number = **20** (calcium).
- (ii) It has 2 valence electrons, so the valency is **2**; it loses them to form Ca^{2+} .
- (iii) It is a **metal**, because it has only a few (two) electrons in its outermost shell and tends to lose them readily, forming a positive ion — the characteristic behaviour of metals.

Case study: In a repeat of the gold-foil experiment, a student uses aluminium foil instead of gold, and finds that far fewer α -particles bounce back. (i) Suggest a reason. (ii) What would happen if a much thicker foil were used? (iii) Why was a very thin foil essential in the original experiment?

SOLUTION

- (i) Aluminium has a much smaller atomic number (13) than gold (79), so its nucleus carries a far smaller positive charge and much less mass. The repulsion it exerts on an α -particle is correspondingly weaker, so far fewer particles are turned back.
- (ii) With a thicker foil, an α -particle would undergo many successive deflections instead of one clean encounter. The scattering pattern would become blurred, and it would be impossible to tell whether a large deflection was due to one close approach or to many small ones.
- (iii) A thin foil ensures that most α -particles interact with **at most one nucleus**. Only then can the angle of deflection be interpreted directly in terms of a single nuclear encounter — which is what allowed Rutherford to deduce the size and charge of the nucleus.

Describe Rutherford's α -scattering experiment: the set-up, the three observations, the conclusion drawn from each, and one drawback of the model he proposed.

SET-UP

- A radioactive source emitted a narrow beam of fast, positively charged α -particles.
- The beam struck an extremely thin gold foil, about 1000 atoms thick.
- A movable zinc-sulfide fluorescent screen surrounded the foil, producing a flash wherever an α -particle struck it, so the direction of every particle could be recorded.

OBSERVATIONS AND CONCLUSIONS

Observation	Conclusion
Most α -particles passed straight through, undeflected	Most of the space inside an atom is empty
A small fraction were deflected through small angles	There is a concentrated positive charge somewhere inside the atom
About 1 in 12,000 was deflected through nearly 180°	All the positive charge and nearly all the mass are packed into a very small central region — the nucleus

DRAWBACK

- The model could not explain the **stability of the atom**: an orbiting electron is an accelerating charge and should radiate energy continuously, spiralling into the nucleus. Bohr resolved this by proposing fixed, non-radiating energy levels.

CHAPTER 9

Atomic Foundations of Matter

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit II — Matter, Its Nature and Behaviour (25 marks)**. Writing chemical formulae and calculating molecular / formula unit mass are guaranteed question types — they are purely mechanical marks once the ion table is memorised.

9.1–9.3 The laws of chemical combination

Law of conservation of mass: in a chemical reaction, the total mass of the reactants equals the total mass of the products.

Law of constant proportions: a pure chemical compound always contains the same elements combined in a fixed ratio by mass.

- Water from any source — rain, sea, tap or lab — always has hydrogen and oxygen in the mass ratio **1 : 8**.
- Ammonia always has nitrogen and hydrogen in the ratio 14 : 3; carbon dioxide always has carbon and oxygen in the ratio 3 : 8.

Dalton's atomic theory (1808)

- All matter is made of extremely small particles called **atoms**.
- Atoms are indivisible and cannot be created or destroyed in a chemical reaction. (*This postulate explains the law of conservation of mass.*)
- Atoms of a given element are identical in mass and chemical properties.
- Atoms of different elements have different masses and properties.
- Atoms combine in **small whole-number ratios** to form compounds. (*This explains the law of constant proportions.*)

9.4–9.5 How atoms combine, and writing formulae

Point	Ionic (electrovalent) bond	Covalent bond
Formed by	Transfer of electrons from metal to non-metal	Sharing of electron pairs between non-metals
Particles formed	Cations (+) and anions (–)	Molecules
Physical state	Hard crystalline solids	Usually gases, liquids or soft solids
Melting/boiling points	High	Low
Solubility	Soluble in water, insoluble in organic solvents	Usually insoluble in water, soluble in organic solvents
Electrical conduction	Conduct in molten state and in aqueous solution (free ions); not in the solid state (ions fixed in the lattice)	Do not conduct — no free ions
Examples	NaCl, MgO, CaCl ₂	H ₂ , O ₂ , HCl, H ₂ O, CH ₄

Common ions — learn this table

Valency 1	Valency 2	Valency 3
Cations: Na ⁺ , K ⁺ , Li ⁺ , Ag ⁺ , Cu ⁺ , NH ₄ ⁺ Anions: Cl [–] , Br [–] , I [–] , F [–] , OH [–] , NO ₃ [–] , HCO ₃ [–]	Cations: Mg ²⁺ , Ca ²⁺ , Zn ²⁺ , Cu ²⁺ , Fe ²⁺ , Ba ²⁺ Anions: O ^{2–} , S ^{2–} , SO ₄ ^{2–} , CO ₃ ^{2–}	Cations: Al ³⁺ , Fe ³⁺ Anions: N ^{3–} , PO ₄ ^{3–}

Criss-cross method for writing a formula:

- Write the symbols of the two ions side by side, cation first.
- Write the valency of each below its symbol.
- Cross over the valencies as subscripts.
- Reduce the subscripts to the simplest whole-number ratio.
- Enclose a polyatomic ion in brackets if its subscript is greater than 1 — e.g. Al₂(SO₄)₃, Ca(OH)₂.

About the headings in this chapter. Section numbers such as 9.1–9.8 follow the NCERT textbook. The headings without a number — electron-dot structures, naming, the mole concept and nuclear energy — are MLI groupings of textbook content; the topics are in the chapter, but check the printed book for its own section numbers if your teacher refers to them.

Electron-dot (Lewis) structures — how the sharing actually happens

The rule behind every structure. An atom shares electrons until its outermost shell holds **eight** electrons (an **octet**) — except hydrogen, which is satisfied with **two** (a **duplet**). Count how many an atom is short by, and that is the number of bonds it must form.

Molecule	Valence electrons per atom	Short by	Shared pairs	Bond formed	Written as
H ₂	H = 1	1 each (duplet)	1	Single covalent	H – H
Cl ₂	Cl = 7	1 each	1	Single covalent	Cl – Cl
O ₂	O = 6	2 each	2	Double covalent	O = O
N ₂	N = 5	3 each	3	Triple covalent	N ≡ N
HCl	H = 1, Cl = 7	1 and 1	1	Single covalent	H – Cl
H ₂ O	O = 6, H = 1	O short by 2, each H by 1	2	Two single covalent	H – O – H
CH ₄	C = 4, H = 1	C short by 4, each H by 1	4	Four single covalent	H ₄ C, tetrahedral
F ₂	F = 7	1 each	1	Single covalent	F – F
CO ₂	C = 4, O = 6	C short by 4, each O by 2	4 (2 with each O)	Two double covalent	O = C = O
H ₂ S	S = 6, H = 1	S short by 2, each H by 1	2	Two single covalent	H – S – H
NH ₃	N = 5, H = 1	N short by 3, each H by 1	3	Three single covalent	H ₃ N, with one lone pair on N

H₂ — single bond H – H shared pair(s) shown as a line Each H needs 1 electron (duplet). One shared pair.	Cl₂ — single bond Cl – Cl shared pair(s) shown as a line Each Cl has 7 valence electrons. One shared pair.	O₂ — double bond O = O shared pair(s) shown as a line Each O needs 2. Two shared pairs.
N₂ — triple bond N ≡ N shared pair(s) shown as a line Each N needs 3. Three shared pairs.	HCl — single bond H – Cl shared pair(s) shown as a line H shares 1 with Cl. One shared pair.	H₂O — two single bonds H – O – H shared pair(s) shown as a line O shares with two H atoms. Two lone pairs left on O.

Fig. 9.C — Covalent bonding in the common molecules asked in the examination

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

How to answer a "explain the formation of the X₂ molecule" question

1. State the atomic number and write the electronic configuration — e.g. fluorine, Z = 9, configuration 2, 7.
2. State how many valence electrons it has and how many it is short of an octet — 7 valence electrons, short by 1.
3. State that no metal is present to donate electrons, so the atoms **share** instead of transferring.
4. State how many pairs are shared and name the bond — one shared pair, a single covalent bond.
5. Write the structure and conclude that both atoms now have a complete octet — F – F.

Lone pairs count too. In H₂O the oxygen atom keeps **two lone pairs** that are not involved in bonding; in HCl the chlorine keeps three. Examiners often award a mark specifically for showing the lone pairs in the dot structure.

Naming compounds — covalent and ionic

A. Naming covalent compounds — the IUPAC prefix system

- The **first** element keeps its ordinary name.
- The **second** element takes the suffix **-ide**.
- A **prefix** in front of each element states how many atoms of it are present.
- The prefix **mono-** is normally omitted for the *first* element but kept for the second (carbon **monoxide**, not "monocarbon monoxide").

Number of atoms	1	2	3	4	5	6
Prefix	mono-	di-	tri-	tetra-	penta-	hexa-

Formula	Name	Why
CO	Carbon monoxide	One carbon, one oxygen — mono- kept on the second element
CO ₂	Carbon dioxide	Two oxygen atoms
SO ₂	Sulfur dioxide	Two oxygen atoms
SO ₃	Sulfur trioxide	Three oxygen atoms
N ₂ O	Dinitrogen monoxide	Two nitrogen, one oxygen
PCl ₅	Phosphorus pentachloride	Five chlorine atoms
SF ₆	Sulfur hexafluoride	Six fluorine atoms
CCl ₄	Carbon tetrachloride	Four chlorine atoms

B. Naming ionic compounds — no prefixes at all

- Name the **cation (metal) first**, then the **anion** with the -ide ending. NaCl is **sodium chloride**, not "sodium monochloride".
- No prefix is needed because the valencies fix the ratio — there is only one possible compound of sodium and chlorine.
- A polyatomic anion keeps its own name: CaCO₃ is **calcium carbonate**, Ca(NO₃)₂ is **calcium nitrate**, Mg(OH)₂ is **magnesium hydroxide**, CaSO₄ is **calcium sulfate**.

The distinction worth one mark: prefixes are used for **covalent** compounds only. If you write "sodium monochloride" or "calcium dinitrate" you have named an ionic compound as though it were covalent.

9.7–9.8 Molecular mass and formula unit mass

Molecular mass = sum of the atomic masses of all the atoms in one molecule (covalent compounds)

Formula unit mass = sum of the atomic masses of all the atoms in one formula unit (ionic compounds)

Useful atomic masses (u): H 1, C 12, N 14, O 16, Na 23, Mg 24, Al 27, S 32, Cl 35.5, K 39, Ca 40, Fe 56, Cu 63.5, Zn 65, Br 80.

Why "formula unit mass" for ionic compounds? Sodium chloride does not exist as discrete NaCl molecules; it is a giant lattice of Na^+ and Cl^- ions. NaCl only gives the simplest whole-number ratio of the ions, so we speak of a formula unit, not a molecule.

🧮 The mole concept — counting particles by weighing them

Why we need it. Atoms are far too small and far too numerous to count one by one. A chemist cannot count atoms, but can easily **weigh** a sample. The **mole** is the bridge: it lets us turn a mass we can measure into a number of particles we can never count.

The definitions

- One **mole** of any substance contains 6.022×10^{23} particles. This number is the **Avogadro number** (N_0), named after Amedeo Avogadro.
- The particles may be **atoms** (1 mole of carbon = 6.022×10^{23} C atoms), **molecules** (1 mole of water = 6.022×10^{23} H₂O molecules) or **ions** — you must always say *of what*.
- Molar mass (M)** is the mass of one mole of a substance, in **grams per mole (g mol⁻¹)**.
- The key shortcut: the molar mass in **g mol⁻¹** is **numerically equal** to the atomic or molecular mass in **u**. Water has molecular mass 18 u, so 1 mole of water weighs **18 g**.

$$n = m \div M \quad \cdot \quad n = N \div N_0 \quad \cdot \quad m = n \times M \quad \cdot \quad N = n \times N_0$$



$$n = m \div M \quad \cdot \quad n = N \div N_0 \quad \cdot \quad N_0 = 6.022 \times 10^{23} \text{ per mole}$$

M = molar mass in g mol⁻¹, numerically the same as the atomic or molecular mass in u

Never go straight from mass to number of particles — always pass through MOLES.

Fig. 9.D — The mole is the only route between a mass you can weigh and a number of particles

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Worked examples

Example 1

Mass → moles

Calculate the number of moles in 90 g of water. (H = 1 u, O = 16 u)

1. Molecular mass of H₂O = (2 × 1) + 16 = 18 u, so M = 18 g mol⁻¹.

2. $n = m \div M = 90 \div 18$

n = 5 moles of water

Example 2**Moles → particles**

How many molecules are present in 5 moles of water?

1. $N = n \times N_0 = 5 \times 6.022 \times 10^{23}$

$N = 3.011 \times 10^{24}$ molecules of water

Example 3**Mass → particles**

Find the number of atoms in 12 g of carbon. ($C = 12 \text{ u}$)

1. M of carbon = 12 g mol^{-1} , so $n = 12 \div 12 = 1$ mole.

2. $N = 1 \times 6.022 \times 10^{23}$

6.022×10^{23} carbon atoms

Example 4**Particles → mass**

What is the mass of 3.011×10^{23} atoms of sodium? ($Na = 23 \text{ u}$)

1. $n = N \div N_0 = (3.011 \times 10^{23}) \div (6.022 \times 10^{23}) = 0.5$ mole.

2. $m = n \times M = 0.5 \times 23$

$m = 11.5 \text{ g of sodium}$

Example 5**A trap to avoid**

How many **atoms** are present in 1 mole of carbon dioxide (CO_2)?

1. 1 mole of CO_2 contains 6.022×10^{23} **molecules**.

2. But each molecule contains 3 atoms — one C and two O.

3. Number of atoms = $3 \times 6.022 \times 10^{23}$

1.807×10^{24} atoms

This is the most common slip in the whole topic. Read carefully whether the question asks for **molecules** or for **atoms**.

Quick reference. 1 mole of any gas at STP occupies **22.4 litres**. Molar masses worth remembering: $\text{H}_2 = 2$, $\text{He} = 4$, $\text{C} = 12$, $\text{N}_2 = 28$, $\text{O}_2 = 32$, $\text{H}_2\text{O} = 18$, $\text{CO}_2 = 44$, $\text{NaCl} = 58.5$, $\text{CaCO}_3 = 100 \text{ g mol}^{-1}$.

Where marks are lost. Writing "1 mole of oxygen" without saying whether you mean oxygen **atoms** (16 g) or oxygen **molecules**, O_2 (32 g). Forgetting the unit $g\ mol^{-1}$ on molar mass. And multiplying mass by N_0 directly, skipping the mole step.

⚙ Energy locked inside the atom

- Ordinary chemical reactions only rearrange the **electrons** of atoms — the nucleus is untouched, and the energy released is comparatively small.
- In a **nuclear** reaction the **nucleus itself** changes, and the energy released is enormously larger. This energy is used to raise steam and drive turbines in nuclear power plants, and also in medicine, research and space exploration.
- Because a nuclear plant does not burn fossil fuel, it releases no carbon dioxide while generating — but it produces radioactive waste that must be stored safely for a very long time.

Indian Knowledge Systems link. In India, **Raja Ramanna** is often called the father of the Indian nuclear programme. He led the work that established India's capability and argued consistently for the **peaceful use of atomic energy** for national development — power generation, medicine and research.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

3 Marks

Element A has one electron in its third shell; element B has six electrons in its second shell. Answer (i) to (vi).

IDENTIFYING THE ELEMENTS

- **A:** configuration 2, 8, 1 → atomic number 11 → **sodium**
- **B:** configuration 2, 6 → atomic number 8 → **oxygen**

ANSWERS

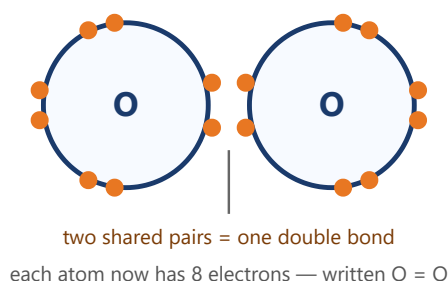
- **(i)** A has one electron in its outermost shell; it is far easier to **lose 1 electron** than to gain seven. So A gives away 1 electron.
- **(ii)** Losing one electron leaves a net charge of +1, so A forms a **cation, A^+** (Na^+).
- **(iii)** B has six valence electrons and needs two more to complete its octet, so it **takes 2 electrons**.
- **(iv)** Gaining two electrons gives a net charge of -2, so B forms an **anion, B^{2-}** (O^{2-}).
- **(v)** Since electrons are completely **transferred** from a metal to a non-metal, the bond formed is **ionic (electrovalent)**.
- **(vi)** Two A^+ ions are needed to balance one B^{2-} ion, so the formula is **A_2B** (Na_2O).

Element X has six electrons in its outer shell and forms a diatomic molecule. A second element Y has two electrons in its outermost shell and a total of three shells. Answer (i) to (iv).

SOLUTION

- (i) X needs **two more electrons** to complete its octet. Since there is no metal available to donate them, two atoms of X each share two of their electrons with the other. Both atoms then effectively have eight electrons, so X exists as the stable diatomic molecule X_2 . (X is **oxygen**, configuration 2, 6.)
- (ii) The electrons are **shared**, not transferred, so the bond is **covalent** — specifically a **double covalent bond**, since two pairs are shared.
- (iii) **Structure of X_2** : $O = O$, with two shared pairs between the atoms and two lone pairs on each atom.
- (iv) Y has two electrons in its outermost shell, i.e. configuration 2, 8, 2 $\rightarrow$ atomic number 12, **magnesium**. Y **loses** its two valence electrons to form Mg^{2+} and X **gains** two to form O^{2-} , so they combine in a 1 : 1 ratio giving **YX (MgO)**, an ionic compound.
- **A caution worth knowing.** If Y had been the element with configuration 2, 2 (beryllium, $Z = 4$), the compound BeO would *not* be a good example of ionic bonding. The Be^{2+} ion is extremely small and highly charged, so it pulls the electron cloud of O^{2-} strongly towards itself and the bond turns out to be largely **covalent**. For a clean ionic example always choose a larger metal ion — Mg, Ca or Na.

Oxygen molecule, O_2 — covalent (double) bond



Magnesium oxide, MgO — ionic bond

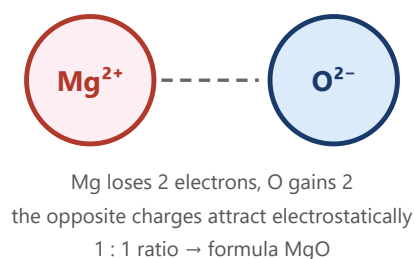


Fig. 9.A — Electron-dot structure of the oxygen molecule and the ionic compound MgO

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Q3

1 Mark

You want an ionic compound with total positive charge $6+$ and total negative charge $6-$. Which combination is correct?

(iii) 2Fe^{3+} and 3O^{2-}

CHECKING EACH

- (i) $2 \text{Al}^{3+} = 6+$, but $3 \text{Cl}^- = \text{only } 3-$. Not balanced.
- (ii) $3 \text{Mg}^{2+} = 6+$, but $1 \text{PO}_4^{3-} = \text{only } 3-$. Not balanced.
- (iii) $2 \times 3+ = 6+$ and $3 \times 2- = 6-$. **Balanced** — this gives Fe_2O_3 .
- (iv) $3 \text{Ca}^{2+} = 6+$, but $2 \text{SO}_4^{2-} = \text{only } 4-$. Not balanced.

Q4

3 Marks

Choose the correct statement(s) and correct the false ones.

(iv) is correct

CORRECTIONS

- (i) **False.** The statement is reversed. Elements may consist of atoms or of molecules of the same kind; compounds are made of molecules (or formula units) containing atoms of **different** elements.
Corrected: "Elements are made up of atoms of one kind; compounds are made up of atoms of two or more different elements chemically combined."
- (ii) **False.** A molecule of a compound must contain atoms of **different** kinds; molecules made of the same kind of atom belong to elements.
Corrected: "The molecule of a compound is always made up of two or more atoms of different kinds."
- (iii) **False.** Nitrogen gas is diatomic, N_2 .
Corrected: "One molecule of nitrogen gas contains two nitrogen atoms."
- (iv) **True.** In water, two hydrogen atoms are covalently bonded to one oxygen atom — H_2O .

Q5

3 Marks

Write the chemical formulae for (i) aluminium nitrate, (ii) calcium oxide, (iii) ferric oxide.

SOLUTION

- (i) **Aluminium nitrate:** Al^{3+} and $\text{NO}_3^- \rightarrow$ three nitrate ions per aluminium ion $\rightarrow \text{Al}(\text{NO}_3)_3$ (brackets because the subscript on a polyatomic ion exceeds 1)
- (ii) **Calcium oxide:** Ca^{2+} and $\text{O}^{2-} \rightarrow$ criss-cross gives Ca_2O_2 , which reduces to **CaO**
- (iii) **Ferric oxide:** "ferric" means Fe^{3+} ; with O^{2-} the criss-cross gives **Fe_2O_3**

Q6

2 Marks

Write the formulae of compounds formed from (i) Ca^{2+} and Br^- , (ii) Al^{3+} and CO_3^{2-} , (iii) K^+ and SO_4^{2-} , (iv) NH_4^+ and Cl^- .

SOLUTION

- (i) CaBr_2
- (ii) $\text{Al}_2(\text{CO}_3)_3$
- (iii) K_2SO_4
- (iv) NH_4Cl

Q7

1 Mark

Which diagram in Fig. 9.18 correctly represents the Cl^- ion (atomic number of chlorine = 17)?

(ii)

REASON

- A neutral chlorine atom has 17 electrons: 2, 8, 7.
- The Cl^- ion has **gained one electron**, so it has 18 electrons arranged as **2, 8, 8**, with the nucleus still holding 17 protons.
- The correct diagram is therefore the one showing a complete octet in the outermost shell together with 17 protons and an overall charge of -1 .

Q8

3 Marks

Determine the formula unit mass of (i) NH_4NO_3 , (ii) H_3PO_4 , (iii) NaHCO_3 .

SOLUTION

- (i) Ammonium nitrate, NH_4NO_3

$$\text{N: } 2 \times 14 = 28$$

$$\text{H: } 4 \times 1 = 4$$

$$\text{O: } 3 \times 16 = 48$$

$$\text{Total} = 28 + 4 + 48 = \mathbf{80 \text{ u}}$$

- (ii) Phosphoric acid, H_3PO_4

$$\text{H: } 3 \times 1 = 3$$

$$\text{P: } 1 \times 31 = 31$$

$$\text{O: } 4 \times 16 = 64$$

$$\text{Total} = 3 + 31 + 64 = \mathbf{98 \text{ u}}$$

- (iii) Sodium hydrogencarbonate, NaHCO_3

$$\text{Na: } 23, \text{H: } 1, \text{C: } 12, \text{O: } 3 \times 16 = 48$$

$$\text{Total} = 23 + 1 + 12 + 48 = \mathbf{84 \text{ u}}$$

Q9

2 Marks

Write the formulae for the compounds formed by (i) magnesium and nitrogen, (ii) lithium and nitrogen, (iii) sodium and sulfur, (iv) aluminium and oxygen.

SOLUTION

- (i) Mg^{2+} and $\text{N}^{3-} \rightarrow \mathbf{Mg_3N_2}$
- (ii) Li^+ and $\text{N}^{3-} \rightarrow \mathbf{Li_3N}$
- (iii) Na^+ and $\text{S}^{2-} \rightarrow \mathbf{Na_2S}$
- (iv) Al^{3+} and $\text{O}^{2-} \rightarrow \mathbf{Al_2O_3}$

Q10

4 Marks

Complete Table 9.3 with the formulae of the compounds formed.

COMPLETED TABLE

	NO_3^-	SO_4^{2-}	PO_4^{3-}
NH_4^+	NH_4NO_3	$(\text{NH}_4)_2\text{SO}_4$	$(\text{NH}_4)_3\text{PO}_4$
Li^+	LiNO_3	Li_2SO_4	Li_3PO_4
Al^{3+}	$\text{Al}(\text{NO}_3)_3$	$\text{Al}_2(\text{SO}_4)_3$	AlPO_4
Cu^{2+}	$\text{Cu}(\text{NO}_3)_2$	CuSO_4	$\text{Cu}_3(\text{PO}_4)_2$

Watch the brackets: they are used whenever a **polyatomic** ion is taken more than once — $(\text{NH}_4)_2\text{SO}_4$, $\text{Al}(\text{NO}_3)_3$, $\text{Cu}_3(\text{PO}_4)_2$. AlPO_4 needs none because 3+ and 3– cancel exactly.

Q11

3 Marks

5.3 g sodium carbonate and 6.0 g acetic acid react to produce 2.2 g carbon dioxide, 0.9 g water and 8.2 g sodium acetate. Verify the law of conservation of mass.

SOLUTION

- **Total mass of reactants** = $5.3 + 6.0 = 11.3 \text{ g}$
- **Total mass of products** = $2.2 + 0.9 + 8.2 = 11.3 \text{ g}$
- Mass of reactants = mass of products
- Hence the **law of conservation of mass is verified** — in a chemical reaction, matter is neither created nor destroyed; the atoms are only rearranged.

Q12

3 Marks

A species has 11 protons, 12 neutrons and 10 electrons. Answer (i) to (iv).

SOLUTION

- (i) Atomic number Z = number of protons = **11**; mass number $A = 11 + 12 = 23$
- (ii) Protons (11, positive) exceed electrons (10, negative) by one, so the species carries a net charge of **+1** — it is a **cation**. It was formed when the neutral atom lost one electron.
- (iii) With 10 electrons, the configuration is **2, 8** — a stable octet, the same as neon.
- (iv) $Z = 11$ is sodium, so the species is the **sodium ion, Na^+** .

Q13

3 Marks

A: 2, 8, 5 and B: 2, 8, 7. (i) Which is more reactive? (ii) Ionic or covalent bond? (iii) Predict the formula of the compound.

SOLUTION

- (i) **B is more reactive.** B needs only **one** electron to complete its octet, whereas A needs three. The fewer electrons an atom must gain, the more readily it reacts. (A is phosphorus, B is chlorine.)
- (ii) Both A and B are **non-metals**, so neither can donate electrons outright. They therefore **share** electrons — the bond is **covalent**. A shares each of its three valence electrons with a separate B atom, so that A reaches eight electrons and each B also reaches eight.
- (iii) Since A needs three electrons and each B supplies a share of one, three B atoms combine with one A atom → formula **AB₃** (PCl₃).

Q14

1 Mark

Assertion (A): Copper sulfate conducts electricity in the molten state but not in the solid state. Reason (R): Copper and sulfate ions are fixed in the lattice in the molten state, while in the solid state they can move freely.

(iii) A is true, but R is false

EXPLANATION

- The assertion is correct — ionic compounds conduct only when their ions are free to move.
- The reason states the exact opposite of the truth: in the **solid** state the ions are held rigidly in the crystal lattice and cannot move, while in the **molten** state the lattice breaks down and the ions become mobile.

Q15

3 Marks

^{27}Al , $^{80}\text{Br}^-$ and $^{201}\text{Hg}^{2+}$ have 13, 35 and 80 protons respectively. How many electrons and neutrons do they have?

SOLUTION

Species	Protons	Electrons	Neutrons = A – Z
^{27}Al (neutral)	13	13	$27 - 13 = 14$
$^{80}\text{Br}^-$ (gained 1 e^-)	35	$35 + 1 = 36$	$80 - 35 = 45$
$^{201}\text{Hg}^{2+}$ (lost 2 e^-)	80	$80 - 2 = 78$	$201 - 80 = 121$

Forming an ion changes only the number of **electrons**. Protons and neutrons are in the nucleus and are unaffected, so the mass number never changes when an ion forms.

E1**1 Mark**

The formula of aluminium sulfate is

(i) $AlSO_4$ (ii) Al_2SO_4 (iii) $Al_2(SO_4)_3$ (iv) $Al_3(SO_4)_2$

(iii) $Al_2(SO_4)_3$

E2**1 Mark**

The law of constant proportions was proposed by

(i) Lavoisier (ii) Proust (iii) Dalton (iv) Berzelius

(ii) Proust

E3**1 Mark**

Which of the following contains a covalent bond?

(i) $NaCl$ (ii) MgO (iii) $CaCl_2$ (iv) H_2O

(iv) H_2O

E4**1 Mark**

Assertion (A): Ionic compounds have high melting points.

Reason (R): A large amount of energy is needed to break the strong electrostatic forces holding the ions in the lattice.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5**2 Marks**

Calculate the molecular mass of (i) $CaCO_3$ and (ii) $C_{12}H_{22}O_{11}$ (sugar).

SOLUTION

- (i) $Ca\ 40 + C\ 12 + O\ (3 \times 16 = 48) = 100\ u$
- (ii) $C\ (12 \times 12 = 144) + H\ (22 \times 1 = 22) + O\ (11 \times 16 = 176) = 342\ u$

E6**2 Marks**

Why do ionic compounds conduct electricity in solution but not in the solid state?

SOLUTION

- In the solid state the ions are locked in fixed positions in the crystal lattice and cannot move, so no charge can flow.
- In aqueous solution or the molten state the lattice breaks down, the ions become free to move towards the electrodes, and the compound conducts.

E7**2 Marks**

Water from a river and water prepared in a laboratory were analysed. Both gave hydrogen and oxygen in the mass ratio 1 : 8. Which law does this illustrate, and what does it mean?

SOLUTION

- It illustrates the **law of constant proportions**.
- A given compound always contains the same elements combined in the same fixed ratio by mass, whatever its source or method of preparation.

Explain with an electron-transfer diagram how sodium chloride is formed from sodium (2, 8, 1) and chlorine (2, 8, 7).

SOLUTION

- Sodium has one valence electron; it loses it and attains the stable configuration 2, 8, becoming Na^+ .
- Chlorine has seven valence electrons; it gains that one electron and attains 2, 8, 8, becoming Cl^- .
- The oppositely charged ions are then held together by a strong **electrostatic force of attraction** — the ionic bond — giving NaCl.
- In the solid, each Na^+ is surrounded by six Cl^- ions and vice versa, forming a giant lattice rather than discrete molecules.



Both ions now carry a stable octet, and the opposite charges hold them together in a giant lattice

Fig. 9.B — Formation of sodium chloride by the transfer of one electron

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Write the formulae of: (i) zinc sulfate, (ii) calcium hydroxide, (iii) ammonium sulfate, (iv) magnesium nitrate, (v) potassium carbonate, (vi) iron(III) chloride.

SOLUTION

- (i) ZnSO_4 (ii) Ca(OH)_2 (iii) $(\text{NH}_4)_2\text{SO}_4$
- (iv) $\text{Mg(NO}_3)_2$ (v) K_2CO_3 (vi) FeCl_3

E10**3 Marks**

In a reaction, 12 g of carbon burns completely in 32 g of oxygen. What mass of carbon dioxide is formed? Which law is used, and what would you conclude if only 40 g were obtained?

SOLUTION

- By the **law of conservation of mass**, mass of products = mass of reactants = $12 + 32 = 44$ g of CO_2 .
- If only 40 g were collected, the law has not been broken — 4 g of gas must have escaped from the apparatus, or some carbon remained unburnt.
- The experiment would need to be repeated in a **closed system** so that no product can escape.

E11**4 Marks**

Case study: A student tests three white solids P, Q and R. P melts at 801°C and conducts electricity when dissolved in water. Q melts at 80°C and its solution does not conduct. R does not melt below 1000°C and conducts only when molten. (i) Which are ionic? (ii) Which is covalent? (iii) Why does R not conduct as a solid? (iv) Predict whether Q dissolves better in water or in kerosene.

SOLUTION

- **(i) P and R** are ionic — both have very high melting points and conduct when their ions are free to move.
- **(ii) Q** is covalent — a low melting point and a non-conducting solution show there are no ions present.
- **(iii)** In solid R the ions are held rigidly in the crystal lattice and cannot migrate; only on melting does the lattice break down and the ions become mobile.
- **(iv)** Q is covalent, so it will dissolve better in **kerosene**, a non-polar organic solvent, than in water. Ionic solids show the opposite preference.

State Dalton's atomic theory and explain how it accounts for (a) the law of conservation of mass and (b) the law of constant proportions. Mention two of its limitations.

THE POSTULATES

- All matter is made of very small particles called atoms.
- Atoms are indivisible and cannot be created or destroyed in a chemical reaction.
- Atoms of a given element are identical in mass and chemical properties.
- Atoms of different elements differ in mass and properties.
- Atoms combine in small whole-number ratios to form compounds.

HOW IT EXPLAINS THE LAWS

- **(a) Conservation of mass:** since atoms are neither created nor destroyed but only rearranged, the same atoms present before the reaction are present after it, so the total mass cannot change.
- **(b) Constant proportions:** since a given compound always contains the same kinds of atoms in the same fixed whole-number ratio, and each kind of atom has a fixed mass, the elements must always be present in the same ratio by mass.

LIMITATIONS

- Atoms are **not indivisible** — they are made of electrons, protons and neutrons.
- Atoms of the same element are **not always identical in mass** — isotopes exist; and atoms of different elements can have the same mass number (isobars).

CHAPTER 10

Sound Waves: Characteristics and Applications

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit III — Motion, Force, Work and Sound (23 marks)**. Sound reliably contributes 5–6 marks, usually one numerical on $v = f\lambda$ or on echo distance, plus a conceptual question on echo, reverberation or ultrasound applications.

10.1–10.2 Production and propagation of sound

- Sound is produced by **vibrating objects** — a tuning fork, a stretched string, the vocal cords, a drum membrane.
- Sound is a **mechanical wave**: it needs a **material medium** to travel and cannot pass through a vacuum.
- Sound is a **longitudinal wave** — the particles of the medium vibrate **parallel** to the direction in which the wave travels, producing regions of **compression** (high density and pressure) and **rarefaction** (low density and pressure).
- Only the **disturbance in density travels forward**; the particles of the medium merely oscillate about their mean positions and are not carried along.
- It travels through solids, liquids and gases — fastest in solids, slowest in gases, because the particles are most closely packed in solids.

Bell-jar experiment: as air is pumped out of a jar containing a ringing electric bell, the sound grows fainter and finally becomes inaudible, although the hammer is still seen striking. This proves sound cannot travel through a vacuum.

10.3 Characteristics of a sound wave

Quantity	Meaning	Symbol & unit
Wavelength	Distance between two consecutive compressions or two consecutive rarefactions	λ , metre (m)
Frequency	Number of complete density oscillations per second at a fixed point	f or ν , hertz (Hz)
Time period	Time taken for one complete oscillation	T , second (s)
Amplitude	Maximum change in density (or pressure) from the average value	A
Speed	Distance travelled by a compression in unit time	v , m s^{-1}
Intensity	Sound energy passing per unit time through unit area held perpendicular to the wave	W m^{-2}

$$v = f\lambda \quad \bullet \quad f = 1/T \quad \bullet \quad v = \lambda/T$$

Characteristic we hear	Depends on
Pitch (shrill or flat)	Frequency — higher frequency means higher pitch
Loudness	Amplitude — larger amplitude means louder sound
Quality (timbre)	Waveform — lets us distinguish a flute from a violin at the same pitch and loudness

Speed of sound (approximate): air at $22^\circ\text{C} \approx 344 \text{ m s}^{-1}$; air at $0^\circ\text{C} \approx 331 \text{ m s}^{-1}$; water $\approx 1500 \text{ m s}^{-1}$; steel $\approx 5000 \text{ m s}^{-1}$. Speed **increases with temperature** and with humidity, but is **independent of frequency** — which is why a band heard from far away still sounds in step.

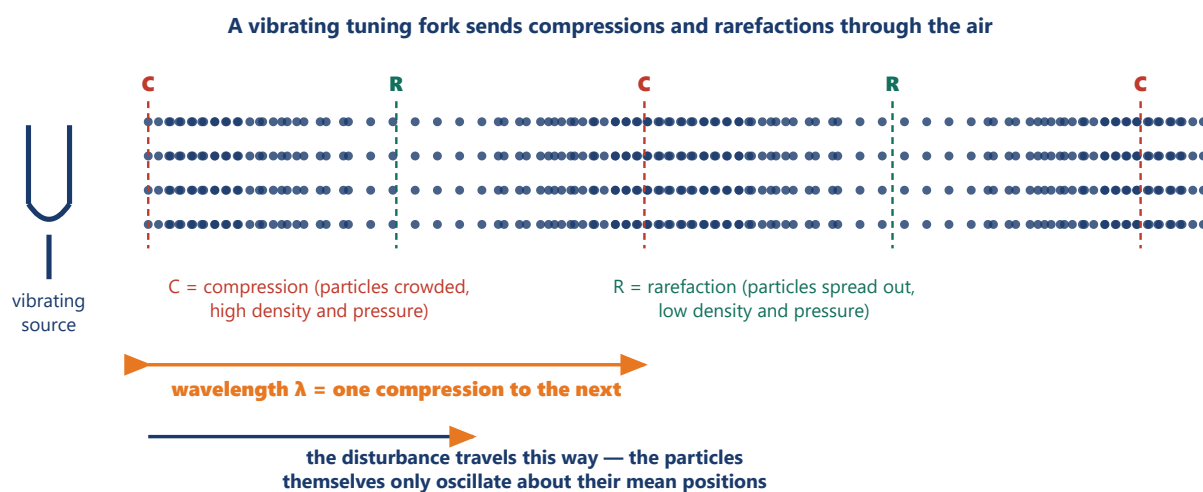


Fig. 10.B — A sound wave is longitudinal: compressions and rarefactions travelling through air

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

10.4–10.6 Reflection of sound: echo and reverberation

- Sound obeys the laws of reflection: the angle of incidence equals the angle of reflection, and the incident ray, the reflected ray and the normal all lie in the same plane.
- The **persistence of hearing** in the human ear is about **0.1 s**. A reflected sound must arrive at least 0.1 s after the original for the two to be heard as separate.

Echo	Reverberation
Reflected sound heard distinctly and separately	Repeated reflections heard as a prolonged, blurred sound
Time gap ≥ 0.1 s	Time gap < 0.1 s
Needs a minimum distance of 17.2 m from the reflector (at 344 m s^{-1})	Occurs in closed halls with hard walls
Example: shouting in a valley or an empty hall	Example: speech in an empty auditorium sounding muddy

For an echo: $2d = v \times t \rightarrow d = vt/2$ (the sound travels to the reflector **and back**)

Reducing reverberation in a hall: cover walls and ceiling with sound-absorbing materials such as heavy curtains, carpets, perforated boards and upholstered seats; the audience itself absorbs a great deal of sound.

Uses of multiple reflection

- Megaphone, loudhailer and horns — a conical tube sends sound forward in one direction instead of letting it spread out.
- Stethoscope — chest sounds reach the doctor's ears by repeated reflection inside the tube.
- Soundboard behind the stage — a curved board reflects sound evenly towards the audience.
- Curved ceilings in concert halls — reflect sound to reach every seat.

10.7–10.8 Range of hearing and applications of ultrasound

 No MLI diagram here — use the NCERT figure

Structure of the human ear

The ear is a three-dimensional structure whose parts sit behind and inside one another. A flat, redrawn sketch cannot show the true positions of the ossicles and the cochlea without distorting them, and a distorted diagram is worse than none — so we are deliberately not drawing one here.

When you open the NCERT figure, make sure you can name:

- Pinna (outer ear) — collects sound
- Ear canal — carries sound inward
- Eardrum (tympanic membrane) — vibrates
- The three ossicles: hammer (malleus), anvil (incus), stirrup (stapes) — amplify the vibration
- Cochlea — converts vibration into nerve signals
- Auditory nerve — carries the signal to the brain

Where to look: the human-ear figure in Chapter 10, Sound Waves: Characteristics and Applications.

Type	Frequency range	Notes
Infrasonic	Below 20 Hz	Produced before earthquakes and by whales, rhinos, elephants; some animals detect these and become restless
Audible	20 Hz – 20,000 Hz	The human hearing range; it narrows with age
Ultrasonic	Above 20,000 Hz	Produced and heard by bats, dolphins, porpoises; used widely in technology

Applications of ultrasound

- **SONAR** (Sound Navigation And Ranging) — measures the depth of the sea, and locates submarines, shipwrecks and shoals of fish, using $d = vt/2$.
- **Medical imaging** — ultrasonography of the abdomen, liver and foetus; echocardiography images the heart.
- **Breaking kidney stones** into fine grains that pass out with urine (lithotripsy).
- **Cleaning** spiral tubes, odd-shaped parts and electronic components in a liquid bath.
- **Detecting flaws** and cracks inside metal blocks that are invisible from outside.
- **Echolocation** — bats navigate and hunt in complete darkness; the same principle is used in vehicle parking sensors.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

1 Mark

Which observation best supports the idea that sound is a mechanical wave?

(ii) Sound needs a medium to propagate

REASON

- A mechanical wave is by definition one that requires a material medium for its propagation.
- Reflection, frequency and the carrying of energy are properties of **all** waves, including electromagnetic ones, so they do not distinguish a mechanical wave.

Q2

1 Mark

For a sound wave propagating in a medium, increasing its frequency will increase its

(iii) number of compressions per second

REASON

- Frequency is the number of oscillations (and hence compressions) crossing a point each second.
- Speed depends only on the medium, so it does not change; and since $v = f\lambda$ is fixed, raising f **decreases** the wavelength. The time period $T = 1/f$ also decreases.

Q3

1 Mark

If 20 compressions pass a point in 4 seconds, the frequency is

(ii) 5 Hz

WORKING

- $f = \text{number of oscillations} \div \text{time} = 20/4 = 5 \text{ Hz}$

Q4

2 Marks

In a room, the reflected sound reaches the ear 0.05 s after its production. Will it produce an echo or reverberation? Justify.

SOLUTION

- The persistence of hearing in the human ear is about **0.1 s**.
- Here the time gap is 0.05 s, which is **less than 0.1 s**.
- The sensation of the original sound has not yet died away when the reflected sound arrives, so the two cannot be heard as separate sounds.
- Therefore it produces **reverberation**, not an echo — the sound is heard as a single, prolonged and slightly blurred sound.
- For an echo, the reflecting surface would need to be at least 17.2 m away, giving a gap of 0.1 s or more.

Q5

2 Marks

Two sound waves are shown in Fig. 10.30 with the same scales. Which has (i) greater wavelength, and (ii) smaller amplitude?

(i) Wave (a) has the greater wavelength (ii) Wave (a) has the smaller amplitude

HOW TO READ SUCH GRAPHS

- **Wavelength** is measured **horizontally** — the distance between two successive density maxima. The curve whose crests are more widely spaced has the greater wavelength.
- **Amplitude** is measured **vertically** — the height of a crest above the average density line. The flatter curve has the smaller amplitude.
- Since the two graphs use the same scales, they can be compared directly by eye.

Three sound waves from sources A, B and C are shown in Fig. 10.31. Frequency of A is maximum and of C is minimum. Identify the curves.

SOLUTION

- All three waves travel in the same medium, so they have the **same speed**; from $v = f\lambda$, frequency and wavelength are **inversely proportional**.
- **A** — maximum frequency → the curve with the **shortest wavelength**, i.e. the crests packed most closely together (the **green** curve in the figure).
- **C** — minimum frequency → the curve with the **longest wavelength**, i.e. the most widely spaced crests (the **blue** curve).
- **B** — the remaining curve, of intermediate wavelength (the **red** curve).

Label them from left to right by counting how many crests fit in the same length of the distance axis — the more crests, the higher the frequency.

Q7

3 Marks

Draw a graph to represent a sound wave for which the density amplitude is 3 units and the wavelength is 4 cm.

HOW TO DRAW IT

- Take **distance (cm)** along the X-axis and **density** along the Y-axis.
- Draw a horizontal line for the **average (normal) density** of the medium.
- Draw a smooth wave that rises **3 units above** the line at a compression and falls **3 units below** it at a rarefaction.
- Space the crests so that the distance from one crest to the next is exactly **4 cm**.

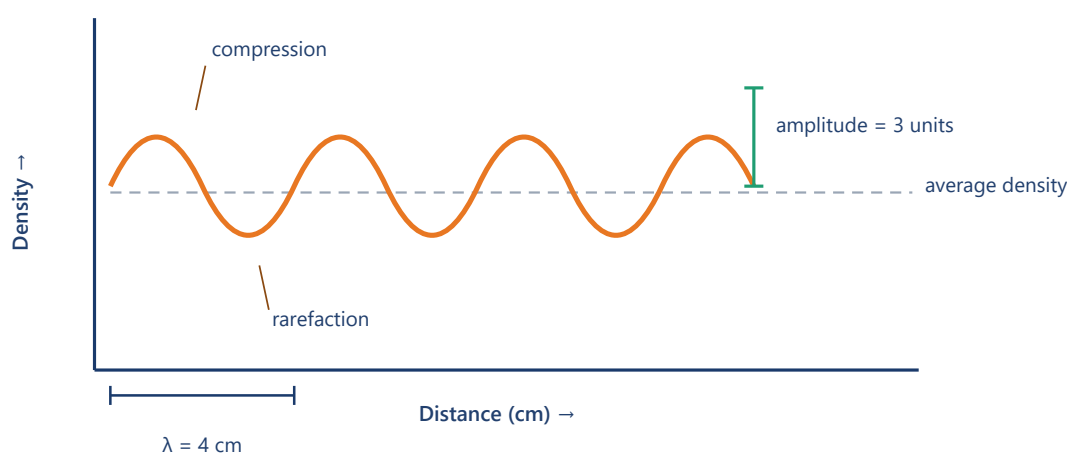


Fig. 10.A — Density–distance graph for a sound wave of amplitude 3 units and wavelength 4 cm

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Q8

3 Marks

A film shows a spacecraft exploding in space with a flash of light and sound at the same time. What are the errors in this depiction?

SOLUTION

- **Error 1 — there should be no sound at all.** Space is very nearly a vacuum. Sound is a mechanical wave and needs a material medium; with no particles to compress and rarefy, it cannot travel. The explosion would be completely silent to a distant observer.
- **Error 2 — even if a medium existed, the light and the sound could not arrive together.** Light travels at $3 \times 10^8 \text{ m s}^{-1}$, roughly a million times faster than sound in air. The flash would be seen long before any sound arrived.
- This is the same reason we see lightning well before we hear thunder, even though both are produced at the same instant.

Q9

2 Marks

A source produces a sound wave of wavelength 3.44 m travelling at 344 m s^{-1} . Find its time period.

SOLUTION

- $v = f\lambda \rightarrow f = v/\lambda = 344/3.44 = 100 \text{ Hz}$
- $T = 1/f = 1/100$

Time period = 0.01 s

Q10

3 Marks

A ship sends a sonar signal and detects the echo after 5 s. If the ultrasonic wave travels at 1525 m s^{-1} in seawater, how deep is the wreck?

SOLUTION

- In 5 s the signal travels **down to the wreck and back**, so it covers twice the depth.
- Total distance = $v \times t = 1525 \times 5 = 7625 \text{ m}$
- Depth $d = 7625 \div 2$

Depth of the wreck $\approx 3812.5 \text{ m}$

Q11

3 Marks

A parking sensor emits a 40 kHz ultrasonic wave. The warning beep starts when the obstacle is 1.2 m away. How long does the wave take to travel to the obstacle and back? (speed = 345 m s^{-1})

SOLUTION

- Total path = $2 \times 1.2 = 2.4 \text{ m}$
- $t = \text{distance} / \text{speed} = 2.4 / 345$
- $t = 0.006956... \text{ s}$

Time taken $\approx 0.007 \text{ s}$ (about 7 milliseconds)

The frequency of 40 kHz is not needed for this calculation; it is given only to tell us the wave is ultrasonic, above the 20 kHz limit of human hearing, so the driver does not hear it.

Q12

3 Marks

The speed of sound is 331 m s^{-1} at 0°C and 344 m s^{-1} at 22°C . How much extra time will thunder take to travel 1720 m if the temperature falls from 22°C to 0°C ?

SOLUTION

- At 22°C : $t_1 = 1720 / 344 = 5 \text{ s}$
- At 0°C : $t_2 = 1720 / 331 \text{ s}$
- Extra time = $t_2 - t_1 = 1720/331 - 5 = (1720 - 1655)/331 = 65/331$
- $= 0.1964 \text{ s}$

Extra time = $65/331 \text{ s} \approx 0.2 \text{ s}$

Note the physical meaning: sound travels **more slowly in colder air**, so the thunder is heard slightly later on a cold night than on a warm one for the same distance.

Q13

3 Marks

From the density variation in Fig. 10.32, where 8 cm covers two full waves, and a wave speed of 340 m s^{-1} , calculate the wavelength and frequency.

SOLUTION

- The marked length of 8 cm contains **two complete waves**.
- $\lambda = 8/2 = 4 \text{ cm} = 0.04 \text{ m}$
- $f = v/\lambda = 340 / 0.04 = 8500 \text{ Hz}$

Wavelength = 0.04 m ; Frequency = 8500 Hz

Q14

3 Marks

Waves A and B in Fig. 10.33 travel at the same speed of 345 m s^{-1} . Find the wavelength and frequency of each.

SOLUTION

- From the distance axis, one full wave of **A** occupies 2.5 cm and one full wave of **B** occupies 5.0 cm.
- **Wave A:** $\lambda_A = 2.5 \text{ cm} = 0.025 \text{ m}$
 $f_A = 345 / 0.025 = \mathbf{13,800 \text{ Hz}}$
- **Wave B:** $\lambda_B = 5.0 \text{ cm} = 0.05 \text{ m}$
 $f_B = 345 / 0.05 = \mathbf{6,900 \text{ Hz}}$

Both waves travel at the same speed, so halving the wavelength exactly doubles the frequency — A is one octave above B. Both lie within the audible range of 20 Hz to 20 kHz.

Q15

3 Marks

Two identical sources at A (in air) and B (in water) send sound horizontally to a cliff and back. The time taken to return to A is 4.5 times that to B. Find the ratio of the speeds of sound in air and in water.

SOLUTION

- Both sources are at the same horizontal distance d from the cliff, so each signal travels a total path of $2d$.
- $t_A = 2d/v_{\text{air}}$ and $t_B = 2d/v_{\text{water}}$
- Given $t_A = 4.5 t_B$:
 $2d/v_{\text{air}} = 4.5 \times 2d/v_{\text{water}}$
- Cancelling $2d$: $1/v_{\text{air}} = 4.5/v_{\text{water}} \rightarrow v_{\text{water}} = 4.5 v_{\text{air}}$
- $v_{\text{air}} : v_{\text{water}} = 1 : 4.5 = 2 : 9$

Speed in air : speed in water = 2 : 9

The result agrees with the physics — sound travels much faster in water than in air because water's particles are far more closely packed, so the disturbance is passed on more quickly.

PART C — EXTRA QUESTIONS (SOLVED)

E1

1 Mark

Sound waves are

(i) transverse (ii) longitudinal (iii) electromagnetic (iv) stationary

(ii) longitudinal

E2

1 Mark

The loudness of a sound depends on its

(i) frequency (ii) wavelength (iii) amplitude (iv) speed

(iii) amplitude

E3

1 Mark

The minimum distance from a reflecting surface needed to hear a distinct echo in air is about

(i) 1.72 m (ii) 17.2 m (iii) 34.4 m (iv) 172 m

(ii) 17.2 m

E4**1 Mark**

Assertion (A): Astronauts on the Moon's surface cannot talk to each other directly.

Reason (R): The Moon has no atmosphere, and sound cannot travel through a vacuum.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5**2 Marks**

Distinguish between compression and rarefaction in a sound wave.

SOLUTION

- **Compression** — a region where the particles of the medium are crowded together, so the density and pressure are **above** normal.
- **Rarefaction** — a region where the particles are spread apart, so the density and pressure are **below** normal.

E6**2 Marks**

A sound wave has a frequency of 2 kHz and a wavelength of 35 cm. How long will it take to travel 1.5 km?

SOLUTION

- $v = f\lambda = 2000 \times 0.35 = 700 \text{ m s}^{-1}$
- $t = \text{distance/speed} = 1500/700 = 2.14 \text{ s}$

Time taken $\approx 2.14 \text{ s}$

E7**2 Marks**

Why are the ceilings of concert halls curved?

SOLUTION

- A curved ceiling reflects the sound coming from the stage and spreads it evenly over the whole hall.
- This ensures that sound of adequate loudness reaches every seat, including those farthest from the stage.

E8

3 Marks

A person claps near a cliff and hears the echo after 3 s. If the speed of sound in air is 340 m s^{-1} , how far is the cliff? What would happen if the cliff were only 10 m away?

SOLUTION

- Total path = $v \times t = 340 \times 3 = 1020 \text{ m}$
- Distance to the cliff = $1020/2 = \mathbf{510 \text{ m}}$
- If the cliff were 10 m away, the sound would return in $2 \times 10/340 = 0.059 \text{ s}$, which is less than 0.1 s. The reflected sound would merge with the original, so **no distinct echo** would be heard — only reverberation.

E9

3 Marks

Explain how a bat uses ultrasound to catch its prey in complete darkness.

SOLUTION

- The bat emits high-frequency **ultrasonic** pulses (above 20 kHz) through its mouth or nose as it flies.
- These waves strike obstacles or prey and are **reflected back** to the bat's ears.
- From the **time delay** of each returning echo the bat judges the distance, and from the change in the echo it judges the direction, size and even the movement of the prey.
- This technique is called **echolocation**; the same principle underlies sonar and vehicle parking sensors.

E10

3 Marks

Why does sound travel faster in solids than in gases? Arrange air, water and steel in increasing order of the speed of sound.

SOLUTION

- In a solid the particles are very closely packed and strongly bound, so a disturbance is passed from one particle to the next almost immediately.
- In a gas the particles are far apart and interact only during collisions, so the disturbance is relayed much more slowly.
- Increasing order of speed: **air** ($\approx 344 \text{ m s}^{-1}$) < **water** ($\approx 1500 \text{ m s}^{-1}$) < **steel** ($\approx 5000 \text{ m s}^{-1}$).

Case study: A new school auditorium has bare concrete walls, a flat hard ceiling and a tiled floor. Speakers complain that their voices sound blurred and unclear. (i) Name the defect. (ii) Explain why it occurs. (iii) Suggest three remedies. (iv) Why is the problem much smaller when the hall is full of people?

SOLUTION

- (i) The defect is excessive **reverberation**.
- (ii) Hard, smooth surfaces reflect almost all the sound that reaches them. The sound undergoes repeated reflections and persists in the hall for a long time. Each new syllable overlaps with the reflections of the previous one, so speech becomes blurred.
- (iii) **Remedies:**
 - Cover the walls with sound-absorbing materials — heavy curtains, felt, perforated fibre boards.
 - Carpet the floor and use upholstered seats.
 - Fit a false ceiling of absorbent material, and use a curved soundboard behind the stage to direct sound towards the audience rather than letting it bounce around.
- (iv) Clothing, hair and human bodies are excellent absorbers of sound. A full hall therefore absorbs most of the sound that would otherwise be reflected, and the reverberation time falls sharply.

Define echo. Derive the expression for the minimum distance required to hear a distinct echo, and list any three practical applications of the reflection of sound.

DEFINITION

- An **echo** is the sound heard after reflection from a distant obstacle, distinctly separate from the original sound.

DERIVATION OF THE MINIMUM DISTANCE

- The sensation of a sound persists in the human ear for about $t = 0.1$ s.
- To be heard separately, the reflected sound must take at least 0.1 s to return.
- In that time the sound travels to the obstacle **and back**, a total of $2d$.
- $2d = v \times t = 344 \times 0.1 = 34.4$ m
- $d = 34.4/2 = \mathbf{17.2\text{ m}}$
- (At a different air temperature the speed changes slightly, so this minimum distance changes a little too.)

APPLICATIONS OF REFLECTION OF SOUND

- **Megaphone / horn:** a conical tube repeatedly reflects sound so that it travels forward in one direction without spreading out.
- **Stethoscope:** the sounds of the heart and lungs reach the doctor's ears by multiple reflections inside the tube.
- **SONAR:** the echo of an ultrasonic pulse is used to find the depth of the sea and to locate submarines, shipwrecks and shoals of fish.

CHAPTER 11

Reproduction: How Life Continues

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit I — World of Living (27 marks)**. Pollination types, asexual methods and the structure of a flower are frequent question sources; the human reproductive system and menstrual cycle usually appear as reasoning questions.

11.1 Why do organisms reproduce?

- Reproduction is the process by which living organisms produce new individuals of their own kind.
- It is **not essential for the survival of the individual**, but it is essential for the **continuity of the species**.
- It ensures transfer of hereditary material (DNA) from one generation to the next.
- Small variations that arise during reproduction are the raw material of **evolution**.

11.2 Asexual reproduction

Only **one parent** is involved; no gametes and no fertilisation. The offspring are **clones** — genetically identical to the parent — because they arise purely by mitosis.

Method	What happens	Examples
Binary fission	Parent divides into two equal daughter cells	Amoeba, Paramecium, bacteria, Leishmania
Multiple fission	Parent divides into many daughter cells at once	Plasmodium
Budding	A bud grows out of the parent body and detaches	Yeast, Hydra
Fragmentation	Body breaks into pieces, each growing into a new individual	Spirogyra, Planaria
Regeneration	A cut part regrows the whole organism	Planaria, Hydra, starfish
Spore formation	Spores are released and germinate in favourable conditions	Rhizopus, ferns, mosses
Vegetative propagation	New plants from root, stem, leaf or bud	Potato (eyes of the tuber), ginger, sugarcane, rose (cutting), <i>Bryophyllum</i> (leaf margins)

Artificial vegetative propagation

- **Cutting** — rose, sugarcane, bougainvillea. **Layering** — jasmine, strawberry. **Grafting** — mango, apple, citrus.
- **Tissue culture** — a few cells from the growing tip are grown in a nutrient medium into a callus, which is then induced to form plantlets. It produces thousands of identical, disease-free plants very quickly, in a small space and in any season — widely used for orchids, banana and ornamental plants.

Advantages of vegetative propagation	Disadvantages
Plants bear flowers and fruits earlier than seed-grown ones	No genetic variation — the whole crop is a clone
Desirable characters of the parent are retained exactly	One disease or pest can wipe out the entire plantation
Useful for plants that produce few or no viable seeds (banana, orange, rose)	Crowding, as new plants grow close to the parent
Faster and cheaper multiplication	Little ability to adapt to changing conditions



11.3 Sexual reproduction in flowering plants

 **No MLI diagram here — use the NCERT figure**

Longitudinal section of a flower

A flower L.S. must show the ovules inside the ovary and the pollen tube growing down through the style — proportions that a simplified sketch gets wrong very easily. Use the printed figure and copy it by hand instead.

When you open the NCERT figure, make sure you can name:

- Sepal and petal
- Stamen = anther + filament (the male part)
- Carpel/pistil = stigma + style + ovary (the female part)
- Ovule inside the ovary
- The pollen tube growing from stigma through style to the ovule
- After fertilisation: ovule → seed, ovary → fruit

Where to look: the flower structure and fertilisation figures in Chapter 11, Reproduction: How Life Continues.

Parts of a flower

- **Sepals (calyx)** — green; protect the bud.
- **Petals (corolla)** — coloured; attract pollinators.
- **Stamen** (male) = **anther** (makes pollen) + **filament**.
- **Carpel / pistil** (female) = **stigma** (receives pollen) + **style** + **ovary** (contains ovules).
- **Bisexual flower** — both stamens and carpel present (hibiscus, mustard, tomato). **Unisexual flower** — only one of them (papaya, watermelon, maize).

Pollination

Self-pollination	Cross-pollination
Pollen falls on the stigma of the same flower or another flower of the same plant	Pollen is carried to the stigma of a flower on a different plant of the same species
No external agent needed; occurs in bisexual flowers such as wheat, pea, tomato	Needs an agent — insects, birds, wind, water
Offspring almost identical; little variation	Produces greater genetic variation and healthier offspring

Emasculation is the removal of the anthers from a bud before it matures. It prevents self-pollination and is the standard first step in producing a controlled cross.

Fertilisation and after

- The pollen grain germinates on the stigma and grows a **pollen tube** down the style into the ovule.
- The male gamete fuses with the egg — **fertilisation** — forming a diploid **zygote**.

- Zygote → embryo; ovule → **seed**; ovary → **fruit**; sepals, petals, stamens and style usually wither and fall.



11.4–11.5 Reproduction in human beings

- **Puberty** — the age (about 10–14 years) at which the reproductive organs mature and secondary sexual characters appear, under the control of hormones.
- **Male system:** testes (produce sperm and testosterone; lie in the scrotum, outside the body, because sperm formation needs a temperature slightly below body temperature), vas deferens, seminal vesicle and prostate (add fluid to form semen), urethra, penis.
- **Female system:** a pair of ovaries (produce ova and the hormones oestrogen and progesterone), oviducts or fallopian tubes (site of fertilisation), uterus (where the embryo develops), cervix and vagina.
- **Fertilisation** takes place in the **oviduct**. The zygote divides repeatedly while moving to the uterus, and the resulting ball of cells **implants** in the thickened uterine lining several days later.
- The **placenta** connects the embryo to the uterine wall, supplying oxygen and nutrients and removing wastes. Gestation in humans lasts about **9 months**.

The menstrual cycle

- A roughly **28-day** cycle (it varies from person to person and from month to month).
- The uterine lining thickens each cycle in preparation for a possible pregnancy; an ovum is released at **ovulation**, around the middle of the cycle.
- If the ovum is not fertilised, the thickened lining breaks down and is shed along with blood — this is **menstruation**, lasting about 2–7 days.
- If fertilisation occurs, the lining is retained to nourish the embryo, and menstruation stops for the duration of the pregnancy.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

1 Mark

A flower's anthers are removed before it matures. Later, pollen from another plant of the same species is dusted onto its stigma and seeds are produced. Which process has been ensured here?

(ii) Cross-pollination

REASON

- Removing the anthers (emasculation) makes self-pollination impossible.
- Pollen is then supplied from a **different plant of the same species**, which is precisely the definition of cross-pollination.
- Fertilisation did also occur, since seeds were formed, but fertilisation would have followed either kind of pollination; the step that was deliberately **ensured** by emasculation is cross-pollination. (The printed NCERT key lists option (iii).)

Q2

1 Mark

Arrange the stages of sexual reproduction in plants in the correct order.

(iii) Pollination → (i) Pollen germination on stigma → (ii) Fertilisation → (iv) Formation of zygote

Q3

1 Mark

Assertion (A): The zygote formed after fertilisation immediately attaches to the uterus wall. Reason (R): The uterus wall is always prepared to receive the zygote.

(iv) A is false, but R is true

EXPLANATION

- The assertion is false: the zygote does not attach immediately. It divides repeatedly as it travels down the oviduct and implants in the uterine wall only several days after fertilisation.
- The reason is true in the sense intended — the uterine lining is thickened and made ready in every cycle in anticipation of a possible pregnancy.

Q4**3 Marks**

Why does asexual reproduction produce offspring that are genetically identical to the parent?

SOLUTION

- Asexual reproduction involves a **single parent** — there is no fusion of gametes from two individuals.
- New cells are produced only by **mitosis**, in which the DNA is first replicated exactly and then distributed equally to the daughter cells.
- There is no **meiosis**, so there is no crossing over and no independent assortment of chromosomes — the two chief sources of variation.
- Consequently every offspring receives an exact copy of the parent's genetic material and is a **clone**.
- The only variations that can arise are occasional random **mutations** or small copying errors, which are rare.

Q5**3 Marks**

Explain why the menstrual cycle stops during pregnancy.

SOLUTION

- Menstruation is the shedding of the thickened uterine lining when the released ovum is **not** fertilised.
- During pregnancy the fertilised egg implants in that lining, which must be **retained** to nourish and protect the developing embryo.
- Hormones — chiefly **progesterone**, supported by the developing placenta — maintain the lining and prevent it from breaking down.
- The same hormones also stop further **ovulation**, so no new ovum is released.
- With no lining shed and no new ovum matured, the menstrual cycle is suspended for the whole period of pregnancy, resuming some weeks after childbirth.

Q6**3 Marks**

Why are flowers that bloom at night white or light in colour compared with those that bloom during the day?

SOLUTION

- Night-blooming flowers are pollinated by **nocturnal** agents — moths, bats and night-flying insects.
- In dim light, bright colours cannot be distinguished, but **white and pale surfaces reflect the most available light** (moonlight and starlight) and so stand out clearly against dark foliage.
- This makes the flower easy to locate, increasing the chance of pollination.
- Such flowers usually compensate for the lack of colour with a **strong fragrance**, which carries far at night — as in raat ki rani, jasmine and the moonflower.
- Day-blooming flowers, by contrast, are visited by bees and butterflies, which see colour well in sunlight, so bright colours are the more effective advertisement for them.

Q7

3 Marks

Why do vegetatively propagated plants tend to be more vulnerable to diseases than sexually reproduced plants?

SOLUTION

- All vegetatively propagated plants are **clones** — genetically identical to one another and to the parent.
- Since they share exactly the same genes, they share exactly the same **susceptibilities**. A pathogen that can infect one plant can infect every plant in the field.
- In a sexually produced population there is **genetic variation**, so some individuals are likely to carry resistance and survive an outbreak.
- Vegetative propagation also transmits any **viral or bacterial infection present in the parent** directly to the offspring through the cutting or tuber.
- This is why a single disease can destroy an entire banana or potato plantation, and why tissue-culture material is certified disease-free before use.

Q8

3 Marks

If all flowers in a type of plant were capable only of self-pollination, how would genetic diversity be affected over several generations?

SOLUTION

- Self-pollination brings together gametes from the **same plant**, so both sets of genes come from a single genetic source.
- Over successive generations the population becomes increasingly **homozygous** — the range of gene combinations narrows steadily.
- Genetic diversity therefore **declines sharply**; the population comes to consist of nearly identical individuals.
- **Consequences:** harmful recessive traits become expressed more often (inbreeding depression); vigour, yield and fertility decline; the population loses its ability to adapt to new pests, diseases or changes in climate.
- In the long run such a species is at greater risk of extinction, since natural selection has very little variation to act upon.

Q9

3 Marks

A farmer wants to produce a large number of genetically identical plants quickly. Suggest suitable methods and explain why they are effective.

SUITABLE METHODS

- **Tissue culture (micropropagation)** — the fastest and most productive option.
- **Vegetative propagation by cuttings** — rose, sugarcane, bougainvillea.
- **Layering** — jasmine, strawberry; and **grafting** — mango, citrus, apple.
- Use of tubers, bulbs, rhizomes and suckers — potato, onion, ginger, banana.

WHY THEY ARE EFFECTIVE

- All are forms of **asexual reproduction**, relying only on mitosis, so every plant produced is genetically identical to the parent — the desirable qualities of the selected plant are retained exactly.
- They are much **faster** than raising plants from seed, and the plants flower and fruit earlier.
- Tissue culture in particular yields **thousands of plantlets from a few cells**, in a small space, in any season, and the material can be certified disease-free.
- They also work for plants that produce few or no viable seeds, such as banana and seedless varieties.
- **Caution the farmer should note:** the resulting crop has no genetic variation and is therefore vulnerable to a single disease.

Q10

4 Marks

Suresh prepares slides with pollen grains in sugar solutions of 0%, 2.5%, 5%, 7.5% and 10%. (i) What hypotheses can be tested? (ii) What parameters should be kept the same?

(I) POSSIBLE HYPOTHESES

- The percentage of pollen grains that germinate **depends on the sugar concentration** of the medium.
- There is an **optimum** sugar concentration at which germination is highest, with germination falling on either side of it.
- Pollen grains will not germinate at all in **distilled water (0%)**, because they burst in a hypotonic medium.
- The **length of the pollen tube** increases with sugar concentration up to the optimum and then decreases.
- Very high concentrations are **hypertonic** and inhibit germination by drawing water out of the pollen grain.

(II) PARAMETERS TO KEEP THE SAME

- The **same species and source** of pollen, collected from freshly opened flowers of the same age.
- The **same number of pollen grains** and the same volume of solution on each slide.
- The same **temperature, humidity and light** conditions for all slides.
- The same **duration** of observation before counting, and the same microscope magnification.
- The same method of preparing the slides, the same type of sugar, and the same quality of water used to make every solution.
- Only the sugar concentration should vary — it is the **independent variable**; the percentage germination is the dependent variable; the 0% slide acts as the **control**.

From the pictures and prompts, identify the type of pollination likely in tomato, wheat and papaya.

SOLUTION

Plant	Clue given	Type of pollination
Tomato	The stamens form a cone that covers the stigma	Self-pollination — pollen falls directly onto the enclosed stigma of the same flower
Wheat	The flowers open only after pollination has taken place	Self-pollination — pollination is complete inside the closed floret, so foreign pollen cannot reach the stigma
Papaya	Male and female flowers are borne on different trees	Cross-pollination — pollen must be carried from a male tree to a female tree by insects or wind

The general rule: any arrangement that keeps the anther close to the stigma of the same flower favours self-pollination, while any arrangement that separates them — in space, in time, or on separate plants — forces cross-pollination.

Apple orchards: Place A relies on natural pollinators, Place B adds beekeeping. Fruit setting and fruit drop data are given in Fig. 11.24. Answer (i) to (iv).

(I) HYPOTHESES OF THE RESEARCHER-FARMER GROUP

- Introducing managed honeybee colonies into an apple orchard **increases fruit setting**, because pollination becomes more reliable.
- Adequate pollination **reduces premature fruit drop**, because well-pollinated flowers form well-developed seeds and are retained by the tree.
- The declining apple yield is caused mainly by the shortage of natural pollinators, and can be corrected by supplementing them.

(II) PARAMETERS IN THE EXPERIMENT

- **Independent variable:** the method of pollination — natural pollinators only (A) versus natural pollinators plus managed beehives (B).
- **Dependent variables:** percentage of fruit setting, and percentage of fruit drop.
- **Controlled parameters that should be alike:** apple variety, age and number of trees, soil, irrigation, manure and pesticide schedule, altitude and weather, and the period of observation.

(III) COMPARISON AND ANALYSIS

- **Place B shows a clearly higher percentage of fruit setting** than Place A, because each flower receives far more pollen visits when managed bee colonies are present.
- **Place B shows a clearly lower percentage of fruit drop** than Place A; poorly pollinated flowers in A form few seeds and the tree sheds those developing fruits.
- Taken together — more fruits set and fewer lost — the net marketable yield at Place B is substantially greater.
- Place B also gives the farmer a **second product, honey**, from the same land.

(IV) INFERENCE

- Pollination is the **limiting factor** in apple yield in this region, not soil or irrigation.
- Integrating **beekeeping with apple cultivation** is an effective, low-cost remedy for declining yields caused by the loss of natural pollinators.
- The study also underlines the wider point that conserving pollinator populations is essential to food security, and that mixed farming can raise both income and ecological stability.

Q13

3 Marks

A student claims, "In humans, ovulation always happens on day 14 of the menstrual cycle." Critically examine this claim.

SOLUTION

- **The claim is not correct.** Day 14 is only an **average**, valid for an idealised 28-day cycle; it is not a fixed rule.
- **Reason 1 — cycle lengths differ.** Normal cycles range from about 21 to 35 days. In a 35-day cycle ovulation occurs around day 21, and in a 21-day cycle around day 7. What is relatively more constant is the gap of about 14 days **before the next period**, not after the last one.
- **Reason 2 — cycles vary within the same person.** Stress, illness, travel, strenuous exercise, changes in body weight, hormonal fluctuations and age can all shift the day of ovulation from one month to the next. Cycles are often irregular for the first few years after puberty and again near menopause.
- A scientifically accurate statement would be: "In humans, ovulation usually occurs roughly midway through the cycle, about 14 days before the next menstrual period, though the exact day varies between individuals and between cycles."

PART C — EXTRA QUESTIONS (SOLVED)

E1

1 Mark

The male reproductive part of a flower is the
(i) carpel (ii) stamen (iii) sepal (iv) ovary

(ii) stamen

E2

1 Mark

Fertilisation in humans takes place in the
(i) ovary (ii) uterus (iii) oviduct (iv) vagina

(iii) oviduct

E3

1 Mark

Bryophyllum reproduces vegetatively through its
(i) roots (ii) stem (iii) leaf margins (iv) flowers

(iii) leaf margins

E4

1 Mark

Assertion (A): Testes lie in the scrotum outside the abdominal cavity.

Reason (R): Sperm formation requires a temperature slightly lower than normal body temperature.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5

2 Marks

Why is reproduction essential for a species although an individual can live without it?

SOLUTION

- An individual's survival depends on nutrition, respiration and excretion, not on reproduction.
- But without reproduction no new individuals would be produced, and the species would disappear as its members die — so reproduction is essential for the **continuity of the species** and for the variation on which evolution depends.

E6

2 Marks

Name the parts of a flower that develop into (a) the fruit and (b) the seed.

SOLUTION

- (a) The **ovary** develops into the fruit.
- (b) The **ovule** develops into the seed, and the zygote within it becomes the embryo.

E7

2 Marks

Differentiate between binary fission and budding with one example each.

SOLUTION

- **Binary fission:** the parent divides into **two roughly equal** daughter individuals and the parent body ceases to exist as such. Example — *Amoeba*.
- **Budding:** a small outgrowth develops on the parent, grows, and detaches; the **parent remains intact**. Example — yeast, *Hydra*.

E8

3 Marks

List three adaptations of flowers that are pollinated by insects and three of flowers that are pollinated by wind.

SOLUTION

Insect-pollinated	Wind-pollinated
Large, brightly coloured, scented petals	Small, dull, scentless flowers
Nectar produced as a reward	No nectar
Pollen sticky or spiny, produced in moderate amounts; stigma sticky and enclosed	Pollen light, smooth and abundant; anthers and feathery stigmas hang out in the air

E9

3 Marks

State three advantages and two disadvantages of vegetative propagation.

ADVANTAGES

- The desirable characters of the parent plant are retained exactly.
- The plants flower and bear fruit much earlier than seed-grown plants.
- It is the only practical method for plants that produce few or no viable seeds, such as banana, rose and seedless grapes.

DISADVANTAGES

- No genetic variation, so the crop cannot adapt and a single disease can destroy it entirely.
- New plants grow close to the parent, causing crowding and competition for water, minerals and light.

E10

3 Marks

Describe the events that follow pollination, leading to the formation of a seed.

SOLUTION

- The pollen grain lands on the stigma and **germinates**, growing a pollen tube down through the style.
- The pollen tube carries the male gamete to the **ovule** inside the ovary.
- The male gamete fuses with the egg cell — **fertilisation** — producing a diploid **zygote**.
- The zygote divides repeatedly to form the **embryo**; the ovule develops a protective seed coat and becomes the **seed**; the ovary enlarges into the **fruit**.
- The sepals, petals, stamens and style usually wither and drop off.

Case study: A nursery owner multiplies an award-winning rose variety entirely by stem cuttings. After four years a fungal disease appears and destroys almost every plant in the nursery. (i) Which method of reproduction was used? (ii) Why did the disease spread so completely? (iii) How did the plants nonetheless retain the prize-winning qualities? (iv) Suggest one change to reduce the risk in future.

SOLUTION

- **(i)** Asexual reproduction by **vegetative propagation** (stem cuttings).
- **(ii)** Every plant was a **clone** with identical genes, so all had exactly the same susceptibility to the fungus. There was no resistant individual anywhere in the nursery for selection to preserve. Any infection already present in the parent would also have been passed on through the cuttings.
- **(iii)** Because cuttings develop only by **mitosis**, each plant received an exact copy of the parent's genetic material, so flower colour, size and fragrance were reproduced faithfully — this is exactly why growers prefer the method commercially.
- **(iv)** Maintain **genetic diversity**: raise part of the stock from seed or from several different parent lines, use certified disease-free tissue-culture material, and avoid growing a single clone across the entire nursery.

Compare sexual and asexual reproduction on the basis of number of parents, gametes, type of cell division, variation, speed, and adaptive value.

SOLUTION

Basis	Asexual reproduction	Sexual reproduction
Number of parents	One	Usually two
Gametes	Not formed; no fertilisation	Male and female gametes fuse at fertilisation
Cell division	Mitosis only	Meiosis to form gametes, then mitosis in the zygote
Variation	Offspring are clones; variation only from rare mutations	Offspring genetically different from both parents and from one another
Speed and numbers	Rapid; large numbers in a short time	Slower; fewer offspring per cycle
Adaptive value	Successful in a stable, favourable environment; a whole population can be wiped out by one disease	Variation allows adaptation to changing conditions and drives evolution

The trade-off in one line: asexual reproduction buys **speed and reliability**, sexual reproduction buys **variation and long-term survival**.

CHAPTER 12

Patterns in Life: Diversity and Classification

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

Part of **Unit I — World of Living (27 marks)**. The five-kingdom table, the hierarchy of classification and the characteristic features of the major animal phyla and plant groups are the standard question sources; case studies on viruses and on the limits of classification are increasingly common.

12.1 India as a biodiversity hotspot

- India's landscape runs from Himalaya in the north to desert in the west, rainforest in the North East, plateaus in the south and long coastlines on the Arabian Sea and the Bay of Bengal. Each region has its own soil and climate, so together they support a very wide variety of species.
- **Endemic species** are species restricted to one region and found naturally nowhere else. Indian examples: **Nilgiri tahr**, **lion-tailed macaque**, the Indian pitcher plant *Nepenthes khasiana*, and **Neelakurinji**.
- **Biodiversity hotspots** are regions that support a large number of endemic species *and* have already suffered significant habitat loss. Both conditions must be met.
- Global hotspots that include Indian territory: the **Western Ghats**, **Indo-Burma** (including North East India), the **Himalaya**, and **Sundaland** (including the Nicobar Islands).

Common 1-mark trap: a hotspot is not simply "an area with many species". The definition requires high endemism **together with** significant habitat loss.

12.2 How has biodiversity evolved?

- The biodiversity on the Earth today was not always the same.
- Small differences between individuals affected their chances of survival and reproduction, helping some to cope with changed conditions.
- These differences accumulated over many generations and gave rise to new forms of life.
- So today's diversity is the outcome of continuous change over a vast span of time, shaped by the interaction between organisms and their surroundings.

12.3–12.4 Why and how we classify

- **Classification** is the arrangement of organisms into groups on the basis of shared characteristics.
- **Why we need it:** it makes the study of a vast diversity manageable; it reveals relationships and evolutionary history; it allows a new organism to be placed and identified; and it lets information about one member be applied to the group.
- **Characteristics used, in order of importance:**
 - Cell structure — **prokaryotic or eukaryotic** (the most fundamental division).
 - Body organisation — **unicellular or multicellular**.
 - Mode of nutrition — **autotrophic or heterotrophic**.
 - Level of organisation — cells, tissues, organs, organ systems.
 - Body design, symmetry and reproduction.

12.5 Classification systems over time

Period	Proposed by	System
4th century BCE	Aristotle	Artificial system — animals grouped by habitat: land, water and air
1758	Carolus Linnaeus	Two kingdoms — Plantae and Animalia
1866	Ernst Haeckel	Three kingdoms — Protista added for microscopic life
1938	Herbert F. Copeland	Four kingdoms — Monera, Protista, Plantae, Animalia
1969	R. H. Whittaker	Five kingdoms — Monera, Protista, Fungi, Plantae, Animalia
1977	Carl Woese	Three domains — Bacteria, Archaea, Eukarya, based on DNA comparison

Classification keeps changing because science itself is self-correcting. Aristotle's system suited his time; microscopes, staining techniques and later DNA studies revealed organisms and relationships he could not have known about, so the grouping was revised.

India's contribution: the *Rigveda* and the *Brihat Samhita* classified animals by habitat (terrestrial, aquatic, aerial), behaviour patterns and ecological roles.

12.6 The five-kingdom classification (R. H. Whittaker, 1969)

Kingdom	Cell type	Body	Cell wall	Nutrition	Examples
Monera	Prokaryotic (no true nucleus)	Unicellular	Present (not cellulose)	Autotrophic or heterotrophic	Bacteria, cyanobacteria, <i>Mycoplasma</i>
Protista	Eukaryotic	Unicellular	Present in some	Autotrophic or heterotrophic	<i>Amoeba</i> , <i>Paramecium</i> , <i>Euglena</i> , diatoms
Fungi	Eukaryotic	Mostly multicellular (yeast is unicellular)	Present — of chitin	Heterotrophic — saprophytic or parasitic; absorb nutrients	<i>Rhizopus</i> , <i>Penicillium</i> , mushroom, yeast
Plantae	Eukaryotic	Multicellular	Present — of cellulose	Autotrophic (photosynthesis)	Mosses, ferns, mango, wheat
Animalia	Eukaryotic	Multicellular	Absent	Heterotrophic — holozoic (ingest food)	Sponge, earthworm, insects, fish, humans

Locomotion is a useful supporting character but not a decisive one: *Euglena* and *Chlamydomonas* swim yet photosynthesise, and are placed in Protista because they are **unicellular eukaryotes**.

12.6.4 Plant kingdom — the major divisions

Group	Key features	Examples
Thallophyta (algae)	Body not differentiated into root, stem and leaf (a thallus); mostly aquatic	Spirogyra, Ulothrix, Cladophora
Bryophyta	"Amphibians of the plant kingdom"; body differentiated into stem-like and leaf-like parts but no vascular tissue ; need water for reproduction; rhizoids for anchorage	Moss (<i>Funaria</i>), <i>Marchantia</i> , <i>Riccia</i>
Pteridophyta	True roots, stem and leaves; vascular tissue (xylem and phloem) present ; reproduce by spores; no seeds	Fern, <i>Marsilea</i> , horsetail
Gymnosperms	Vascular, bear naked seeds not enclosed in a fruit; usually perennial and evergreen	Pine, <i>Cycas</i> , deodar
Angiosperms	Flowering plants; seeds enclosed in a fruit ; divided into monocots (one cotyledon) and dicots (two)	Mango, wheat, mustard, maize

12.6.5 Animal kingdom — major phyla at a glance

Phylum	Distinguishing features	Examples
Porifera	Pores on the body; no true tissues or organs; sessile; cellular level of organisation	Sponges, <i>Sycon</i>
Coelenterata (Cnidaria)	Radial symmetry; body cavity; tissue level of organisation; stinging cells	<i>Hydra</i> , jellyfish, sea anemone, corals
Platyhelminthes	Flat, bilaterally symmetrical, unsegmented; many parasitic	Tapeworm, liver fluke, <i>Planaria</i>
Nematoda	Cylindrical, unsegmented round worms	<i>Ascaris</i> , filarial worm
Annelida	Body divided into true segments (rings) ; bilateral symmetry	Earthworm, leech, <i>Nereis</i>
Arthropoda	Largest phylum; jointed legs ; chitinous exoskeleton; open circulatory system	Insects, spider, prawn, scorpion
Mollusca	Soft unsegmented body, often with a calcareous shell; muscular foot	Snail, octopus, mussel
Echinodermata	Spiny skin; radial symmetry in adults; marine; water-vascular system	Starfish, sea urchin
Chordata	Notochord, dorsal nerve cord, gill slits at some stage; includes the vertebrates — fish, amphibia, reptiles, birds, mammals	Fish, frog, lizard, pigeon, human

Viruses fall outside the five kingdoms. They have genetic material (DNA or RNA) and a protein coat, but no cell, no cytoplasm, no organelles and no metabolism of their own. They are inert crystals outside a host and reproduce only inside a living cell. Since **cellular organisation** is the very basis of the five-kingdom system, viruses cannot be placed in any of them.

12.7 Adaptations as outcomes of structural change

- The diversity seen in animals today is the outcome of changes in body structure over long periods of time.
- **Fins and gills** let fish move and breathe in water.
- **Feathers and hollow bones** make flight possible in birds.
- **Fat storage in camels** and **thick fur in polar bears** show how structural features support survival in extreme conditions.
- **Mammary glands** in mammals are a structural and functional change that improves the survival of the young.

These features are interconnected: animal diversity reflects the range of body forms found in organisms living under different environmental conditions.

12.7.1 The hierarchical nature of classification

Kingdom → Phylum (Division in plants) → Class → Order → Family → Genus → Species

- Classification moves step by step from very broad groups to smaller, more specific ones.
- At each lower level, organisms share **more** characteristics, and the number of organisms in the group **decreases**.
- Every lower group is part of the group above it — the arrangement works like a postal address.

Level	Tiger	Pea
Kingdom	Animalia	Plantae
Phylum	Chordata	Magnoliophyta
Class	Mammalia	Magnoliopsida
Order	Carnivora	Fabales
Family	Felidae	Fabaceae
Genus	<i>Panthera</i>	<i>Pisum</i>
Species	<i>P. tigris</i>	<i>P. sativum</i>

12.8 Scientific naming — the binomial system

- A tiger is *bagh* in Hindi, *puli* in Tamil, tiger in English and *tigre* in French — common names cause confusion across regions.
- **Binomial nomenclature**, introduced by **Carolus Linnaeus** in the 18th century, gives every organism a two-part scientific name in Latin or a Latinised form.
- The **first** word is the **genus**, the **second** is the **species**.
- A **genus** groups closely related species sharing common features — *Panthera tigris* (tiger) and *Panthera leo* (lion) are both roaring cats with a similar skull structure.
- A **species** is a group of similar individuals capable of interbreeding and producing offspring.

Rules for writing a scientific name

- Two parts — genus followed by species.
- Genus begins with a **capital** letter; species is written in **lower case**.
- Printed in **italics**; **underlined** (separately) when handwritten.

Examples: *Panthera tigris* (tiger), *Mangifera indica* (mango), *Homo sapiens* (human).

12.9 Fossils as evidence

- **Fossils** are preserved remains of plants and animals found in layers of rock, sand and mud.
- Generally, **older layers contain simpler organisms** while **newer layers show more complex forms**.
- Fossils act as natural records showing how life has changed over millions of years — from giant dinosaurs to early humans and ancient plants, several important fossils have been found in India.

Birbal Sahni studied fossil plants and founded the **Birbal Sahni Institute of Palaeosciences (BSIP)**, Lucknow. His work linked present-day plants with their ancestors and showed that life on the Earth has a long, connected history.

12.10 Biodiversity under threat

- Every species has a role: plants produce food and oxygen, animals pollinate flowers and disperse seeds, microorganisms recycle nutrients.
- Human activities — **pollution, deforestation, overuse of resources and climate change** — are reducing biodiversity.
- When one species disappears, others that depend on it may decline and eventually disappear too.

The Purple Frog (*Nasikabatrachus sahyadrensis*) of Kerala is named after the Sahyadri Hills. It lives underground for most of the year and emerges only during the monsoon to breed. Its discovery in 2003 helped scientists understand ancient amphibian groups and highlighted the need for conservation in the Western Ghats.

Phumdis — floating grasslands of Loktak Lake in Keibul Lamjao National Park, Manipur — are among the world's unique habitats. These floating beds of soil and rooted vegetation range from a few centimetres to two metres thick and shelter the endangered Sangai deer.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

1 Mark

Which option confirms that the animal observed is an insect and not an earthworm?

(ii) Body with jointed legs

REASON

- Jointed legs are the defining feature of **Arthropoda**, to which insects belong; earthworms (Annelida) have no legs at all.
- Bilateral symmetry, a cylindrical body and segmentation are shared by both, so none of those can settle the question.

Q2

1 Mark

Which feature of sponge cells supports classification under the animal kingdom?

(iii) Presence of a cell membrane

REASON

- Animal cells are bounded by a plasma membrane and have **no cell wall**; sponge cells match this, which places them in Animalia.
- A cell wall would suggest a plant or a fungus; the ability to photosynthesise would suggest a plant; and absence of mitochondria would rule out a eukaryote altogether.

Q3

3 Marks

Observe two different animals in your environment. What features help you distinguish between them, and how do these place them in different groups?

SAMPLE ANSWER — A HOUSE LIZARD AND A BUTTERFLY

Feature	House lizard	Butterfly
Skeleton	Internal bony skeleton with a backbone	No backbone; hard external skeleton of chitin
Legs	Four limbs with clawed digits	Six jointed legs
Body divisions	Head, trunk and tail	Head, thorax and abdomen
Wings	Absent	Two pairs of scaly wings
Skin	Dry, scaly	Chitinous exoskeleton

HOW THESE FEATURES PLACE THEM

- The presence of a **backbone** puts the lizard in Phylum **Chordata**, subphylum Vertebrata, class **Reptilia**.
- **Jointed legs and a chitinous exoskeleton** put the butterfly in Phylum **Arthropoda**, class **Insecta**.
- This shows how a small number of well-chosen structural features is enough to assign an unknown animal to its group.

Q4

3 Marks

How would a scientist justify choosing cellular organisation, rather than the presence of xylem and phloem, as the more fundamental basis of classification?

SOLUTION

- **Universality:** every living organism is made of cells, so cellular organisation — prokaryotic or eukaryotic, unicellular or multicellular — can be applied to **all** organisms. Vascular tissue exists only in some plants and is meaningless for bacteria, fungi and animals.
- **Fundamental nature:** the presence or absence of a true nucleus and membrane-bound organelles reflects the deepest and earliest division in the history of life, far older than the evolution of conducting tissue.
- **Position in the hierarchy:** cellular organisation separates organisms at the level of **kingdoms**; vascular tissue separates groups only *within* the plant kingdom, so it belongs at a lower level of the hierarchy.
- **Consistency:** a character used at the top of a classification must divide the whole of life without exception. Cellular organisation does; xylem and phloem do not.

Q5**3 Marks**

An unlabelled slide shows a single-celled organism with a well-defined nucleus and multiple cilia. Which group does it most likely belong to? Give reasons.

SOLUTION

- It belongs to the kingdom **Protista** — most likely a ciliate such as *Paramecium*.
- **Reason 1:** the organism is **unicellular**, which rules out Plantae, Animalia and most fungi.
- **Reason 2:** it has a **well-defined nucleus**, so it is **eukaryotic**, which rules out Monera.
- **Reason 3:** the **cilia** are locomotory organelles typical of protists; they also help sweep food particles towards the cell.
- A unicellular eukaryote with organelles for movement fits the definition of Protista exactly.

Q6**3 Marks**

How does the diversity of organisms contribute to the balance and stability of an ecosystem?

SOLUTION

- Diversity ensures that every ecological role is filled — producers, consumers at several levels, and decomposers — so energy flows and nutrients are recycled continuously.
- It produces complex **food webs** rather than simple food chains. If one species declines, others can take its place, so the whole system does not collapse.
- Different species use resources in different ways, which reduces competition and allows more efficient use of light, water and minerals.
- Diversity provides **resilience**: a diverse community recovers faster from drought, disease or other disturbance, because some members are likely to tolerate the new conditions.
- It maintains essential services — pollination, seed dispersal, soil formation, pest control and climate regulation.
- Genetic diversity within species supplies the raw material for adaptation and evolution over the long term.

Q7**3 Marks**

If all unicellular organisms were grouped into a single kingdom, what problems would arise?

SOLUTION

- The group would contain both **prokaryotes** (bacteria, with no true nucleus) and **eukaryotes** (Amoeba, Paramecium, yeast), merging the single deepest and most important distinction in all of biology.
- Organisms with utterly different **modes of nutrition** — photosynthetic, saprophytic, parasitic and holozoic — would be forced together, so nutrition could no longer be used as a classifying character.
- It would obscure **evolutionary relationships**: unicellular yeast is far more closely related to multicellular mushrooms than to a bacterium, yet would be separated from the fungi.
- Multicellular groups would become artificial too, since fungi, algae and animals all include unicellular members that would have to be removed from them.
- The classification would be based on a **single superficial character** (number of cells) rather than on fundamental structure, and would therefore have little predictive value.

Q8**3 Marks**

Why are viruses not placed in any of the five kingdoms?

SOLUTION

- The five-kingdom system is built on **cellular organisation**, and viruses are **acellular** — they consist only of genetic material (DNA or RNA) enclosed in a protein coat.
- They have no cytoplasm, no cell membrane of their own, no ribosomes and no organelles.
- They carry out **no metabolism** — no respiration, no nutrition, no growth, no excretion.
- They cannot reproduce independently; they multiply only by taking over the machinery of a living host cell, and are therefore obligate intracellular parasites.
- Outside a host they can be **crystallised** and remain inert like non-living matter, yet inside a host they show heredity, mutation and multiplication.
- Standing on the borderline between the living and the non-living, they fit none of the five kingdoms.

Q9

4 Marks

If you were to revise the five-kingdom classification, would you create a separate category for viruses or keep them outside? Justify, and explain what this indicates about scientific classification.

A REASONED ANSWER

- **Position taken:** viruses deserve a **separate category of their own**, placed alongside rather than inside the five kingdoms — for example a distinct group of "acellular entities".
- **Justification for a separate category:** viruses are numerous, biologically important and clearly distinct from every cellular group. Leaving them entirely outside makes classification incomplete and gives no systematic way to arrange the thousands of viruses now known.
- **Why not inside the existing five:** placing them in any kingdom would break the defining criterion of that kingdom, since all five are built on the cell.
- **The alternative view, fairly stated:** some biologists argue that classification should cover only living organisms, and that since viruses show no independent life they should be excluded and studied separately.
- **What this reveals:** classification is a **human construct**, not a fixed fact of nature. It is revised whenever new evidence appears — as when two kingdoms became five, and five were later extended by the three-domain system. Boundary cases such as viruses expose the limits of any scheme and drive its improvement. This self-correcting quality is a strength of science, not a weakness.

Q10

3 Marks

Viruses contain genetic material but lack cellular organisation. Which features prevent them from fitting into the five-kingdom system, and what does this tell us about the limitations of classification systems?

FEATURES THAT PREVENT PLACEMENT

- Absence of a cell — no membrane-bound cytoplasm, no organelles, no ribosomes.
- No metabolic activity of their own; no growth, respiration or excretion.
- Inability to reproduce outside a host cell.
- Ability to be crystallised, behaving like non-living chemical matter.

WHAT IT TELLS US ABOUT CLASSIFICATION

- Every classification rests on **chosen criteria**; anything that does not possess those criteria simply cannot be placed, however important it may be.
- Nature is continuous, while classification imposes sharp boundaries — so borderline forms are inevitable.
- Classification systems are therefore **provisional and revisable**, and must be updated as new organisms and new evidence (such as molecular data) come to light.

Q11

3 Marks

Both pteridophytes and bryophytes lack flowers and seeds, yet are placed in different groups. Explain using their key features.

SOLUTION

Feature	Bryophyta	Pteridophyta
Vascular tissue	Absent — no xylem or phloem	Present — true xylem and phloem
Plant body	Thallus-like; only stem-like and leaf-like structures, with rhizoids for anchorage	Differentiated into true roots, stem and leaves
Conduction	Water and food pass slowly from cell to cell	Efficient long-distance conduction through vascular bundles
Size and habitat	Small; restricted to damp, shady places	Can grow much larger; occupy a wider range of habitats
Example	Moss, <i>Marchantia</i> , <i>Riccia</i>	Fern, <i>Marsilea</i> , horsetail

- The decisive difference is the **presence of vascular tissue**, which is a far more fundamental character than the mere absence of flowers and seeds.
- Bryophytes are called the "amphibians of the plant kingdom" because they still need a film of water for fertilisation; pteridophytes were the first true vascular land plants.

Q12

3 Marks

In the classification hierarchy, which group — class or genus — has fewer members but more features in common?

SOLUTION

- Genus.**
- The hierarchy runs Kingdom → Phylum → Class → Order → Family → **Genus** → Species, so genus lies much lower than class.
- As we move down the hierarchy the number of organisms in a group **decreases** while the number of shared characters **increases**.
- A class such as Mammalia contains thousands of species sharing only a few broad features (hair, mammary glands, warm blood). A genus such as *Panthera* contains only a handful of closely related species — tiger, lion, leopard, jaguar — sharing a great many detailed features.
- Members of one genus are therefore far more closely related to one another than members of one class.

Q13**2 Marks**

A new organism shows locomotion and autotrophic nutrition. Which characters would help identify it as a member of Protista?

SOLUTION

- The decisive characters are that it is **unicellular** and **eukaryotic** — a single cell with a true, membrane-bound nucleus and organelles.
- The presence of **locomotory organelles** such as cilia, flagella or pseudopodia supports the placement.
- Autotrophic nutrition by itself does not make it a plant, because Plantae is restricted to **multicellular** organisms.
- The combination of movement with photosynthesis is exactly what is seen in *Euglena* and *Chlamydomonas*, both firmly placed in Protista.

Q14**3 Marks**

A researcher identified a unicellular eukaryotic organism as a fungus. What identification key would you suggest for keeping a unicellular organism in Kingdom Fungi?

SUGGESTED KEY — THE ORGANISM SHOULD SATISFY ALL OF THE FOLLOWING

- **1.** Cell wall present and made of **chitin**, not of cellulose and not of peptidoglycan.
- **2. No chlorophyll** and no plastids — the organism cannot photosynthesise under any light condition.
- **3.** Nutrition is **heterotrophic by absorption** — saprophytic on dead organic matter, or parasitic — and never by ingestion of solid food.
- **4.** Reproduction by **budding or spore formation**, as in yeast.
- **5.** A true nucleus and membrane-bound organelles, confirming it is eukaryotic.
- **6.** No locomotory organelles such as cilia, flagella or pseudopodia.

Points 1 and 3 together are what separate a unicellular fungus such as **yeast** from a unicellular protist such as *Amoeba* (no wall, ingests food) or *Euglena* (photosynthetic, flagellum).

Case study: organisms P, Q, R, S and T with the observations given in the table. Answer (i) to (vii).

SOLUTION

- **(i) Kingdom Fungi — organism Q.** Supporting observation: it is multicellular and filamentous with a cell wall but **no chlorophyll**, and it grows on **dead organic matter** — saprophytic absorption, the defining nutrition of fungi.
- **(ii) Kingdom Monera — organism P.** Justifying characteristic: it has **no true nucleus**, i.e. it is prokaryotic; its rigid covering and tolerance of high salinity and temperature also match the archaea-like members of Monera.
- **(iii) R versus Q.** Both are eukaryotic, but they differ on two decisive criteria:
 - **Body organisation** — R is **unicellular** (Protista) while Q is **multicellular** and filamentous (Fungi).
 - **Mode of nutrition** — R is photosynthetic in light and heterotrophic in the dark (mixotrophic, as in *Euglena*), whereas Q is exclusively saprophytic and can never photosynthesise.
 - R also possesses locomotory flagella and a contractile vacuole; Q is non-motile.
- **(iv) Why S cannot be classified by nutrition alone.** S is heterotrophic, but so are fungi, many protists and many monerans. Heterotrophy is shared by several kingdoms and cannot by itself place an organism. The features that actually place S in Animalia — and further in Chordata — are **multicellularity with well-differentiated tissues, absence of a cell wall, and the presence of a backbone**, with gill-based respiration in the early life stage indicating a fish or an amphibian.
- **(v) Organism T.** T lacks **cellular organisation** — it is acellular and remains inactive outside a host. Since the entire five-kingdom system is founded on the cell, T (a virus) has **no place in it at all**. This reveals that a classification can accommodate only what fits its chosen criteria, and that such systems are provisional and must be revised as new kinds of entity are discovered.
- **(vi) If classification were based only on habitat.** Organisms of completely different structure would be lumped together — for instance, P (a moneran from a hot saline pool), R (a protist from the pond) and S (a fish) could all be called "aquatic", while a whale and a shark would be grouped with them despite a whale being a mammal. The scientific consequences would be serious: evolutionary relationships would be hidden, the scheme would have no predictive value, and organisms occupying more than one habitat in a lifetime (such as amphibians, or S itself) could not be placed at all.
- **(vii) The new organism — multicellular, eukaryotic, no chlorophyll, absorbing nutrients from a host externally — should be placed under Fungi.** The decisive criterion is the **mode of nutrition**: it absorbs dissolved nutrients through its body surface rather than ingesting solid food. Animals are holozoic — they take food in and digest it internally. Confirmation would come from finding a **cell wall of chitin**, which would settle the matter, since animal cells have no cell wall.

PART C — EXTRA QUESTIONS (SOLVED)

E1

1 Mark

The five-kingdom classification was proposed by

(i) Linnaeus (ii) Whittaker (iii) Haeckel (iv) Aristotle

(ii) Whittaker

E2

1 Mark

The cell wall of fungi is made of

(i) cellulose (ii) chitin (iii) peptidoglycan (iv) lignin

(ii) chitin

E3

1 Mark

Plants that bear naked seeds belong to

(i) Bryophyta (ii) Pteridophyta (iii) Gymnosperms (iv) Angiosperms

(iii) Gymnosperms

E4

1 Mark

Assertion (A): Bryophytes are called the amphibians of the plant kingdom.

Reason (R): They live on land but need water for fertilisation.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5

2 Marks

What is binomial nomenclature? Write the rules for writing a scientific name.

SOLUTION

- Binomial nomenclature, introduced by **Carolus Linnaeus**, is the system of giving every organism a two-part Latin name — the genus followed by the species.
- Rules:** the genus name begins with a capital letter and the species name with a small letter; the name is printed in *italics* and underlined separately when handwritten; it is drawn from Latin or latinised words.
Example: *Mangifera indica*.

E6

2 Marks

Give two reasons why classification is necessary.

SOLUTION

- It makes the study of an enormous diversity of organisms systematic and manageable, and allows a newly found organism to be identified and placed.
- It reveals evolutionary relationships, so that knowledge about one member of a group can be extended to its relatives.

E7

2 Marks

Name the phylum to which each belongs: (a) starfish, (b) tapeworm, (c) octopus, (d) earthworm.

SOLUTION

- (a) Echinodermata (b) Platyhelminthes (c) Mollusca (d) Annelida

E8

3 Marks

Differentiate between Monera and Protista on the basis of (i) cell type, (ii) body organisation, (iii) examples.

SOLUTION

Basis	Monera	Protista
Cell type	Prokaryotic — no true nucleus, no membrane-bound organelles	Eukaryotic — true nucleus and organelles present
Body organisation	Unicellular, usually smaller (1–10 µm)	Unicellular, generally larger and more complex
Examples	Bacteria, cyanobacteria, <i>Mycoplasma</i>	<i>Amoeba</i> , <i>Paramecium</i> , <i>Euglena</i> , diatoms

E9

3 Marks

Why is *Euglena* difficult to classify? Where is it finally placed and why?

SOLUTION

- *Euglena* shows a mixture of plant and animal characters: it has **chloroplasts** and photosynthesises in light, like a plant, but it has **no cell wall**, moves using a **flagellum** and feeds heterotrophically in the dark, like an animal.
- It therefore fits neither Plantae nor Animalia, both of which are restricted to multicellular organisms in any case.
- It is placed in **Protista**, because the decisive characters are that it is a **unicellular eukaryote** — which is precisely the definition of that kingdom.

E10

3 Marks

Write the full classification hierarchy of the human being from kingdom to species.

SOLUTION

Kingdom	Animalia
Phylum	Chordata
Class	Mammalia
Order	Primates
Family	Hominidae
Genus	<i>Homo</i>
Species	<i>sapiens</i>

Scientific name: *Homo sapiens*

E11

4 Marks

Case study: A student collects four specimens — W (multicellular, cell wall of cellulose, green, no vascular tissue, grows on damp walls), X (multicellular, no cell wall, jointed legs, chitinous covering), Y (unicellular, no nucleus, rigid wall), Z (multicellular, no cell wall, backbone, feathers). Classify each and give one justification.

SOLUTION

Specimen	Group	Justification
W	Plantae — Bryophyta (a moss)	Multicellular, photosynthetic, cellulose wall, but no vascular tissue ; grows in damp shade
X	Animalia — Arthropoda	Jointed legs with a chitinous exoskeleton, no cell wall
Y	Monera	Unicellular with no true nucleus — prokaryotic
Z	Animalia — Chordata, class Aves	Has a backbone and feathers , which are unique to birds

Describe the five kingdoms of Whittaker's classification, giving the basis of the division and one example of each.

BASIS OF THE DIVISION

- Whittaker used four criteria together: **cell structure** (prokaryotic or eukaryotic), **body organisation** (unicellular or multicellular), **mode of nutrition** (autotrophic or heterotrophic), and **phylogenetic relationships**.

THE FIVE KINGDOMS

- Monera** — prokaryotic, unicellular, with a cell wall that is not of cellulose; nutrition autotrophic or heterotrophic. Example: bacteria.
- Protista** — unicellular eukaryotes, often with cilia, flagella or pseudopodia for locomotion. Example: *Amoeba*, *Euglena*.
- Fungi** — eukaryotic, mostly multicellular, cell wall of chitin, heterotrophic by absorption (saprophytic or parasitic). Example: *Rhizopus*, mushroom.
- Plantae** — multicellular eukaryotes with a cellulose cell wall and chloroplasts; autotrophic. Example: mango tree.
- Animalia** — multicellular eukaryotes without a cell wall; heterotrophic and holozoic; most are motile. Example: human being.

Limitation worth mentioning: the system has no place for viruses, viroids or lichens, and later molecular evidence showed that Monera itself contains two very distinct lines — which led to the modern three-domain system.

CHAPTER 13

Earth as a System: Energy, Matter, and Life

Study Notes · NCERT Solutions (Revise, Reflect, Refine) · Extra Questions

PART A — STUDY NOTES

Weightage

This chapter forms the whole of **Unit IV — Earth as a System (5 marks)**. It is short and entirely descriptive: the biogeochemical cycles, the greenhouse effect and the spheres of the Earth are where the marks are, and a well-labelled cycle diagram often carries 3 of them.

13.1 The spheres of the Earth

Sphere	What it consists of
Geosphere (lithosphere)	The solid outer crust — rocks, soil, minerals, landforms
Hydrosphere	All water — oceans, seas, rivers, lakes, groundwater, water vapour
Atmosphere	The envelope of gases surrounding the Earth — about 78% N ₂ , 21% O ₂ , with CO ₂ , argon and water vapour
Cryosphere	All frozen water — glaciers, ice sheets, sea ice, snow cover, permafrost
Biosphere	All living organisms and the zones they occupy

These spheres are not separate compartments. They exchange matter and energy continuously, and a change in one is transmitted to the others — which is exactly why the Earth is studied as a **system**.

Wording to use in the exam. *Exploration* names the solid Earth the **geosphere**. Many older books call it the **lithosphere**. Strictly, the lithosphere is only the rigid outer shell (crust + upper mantle), while the geosphere means the whole solid Earth down to the core. Write **geosphere** when listing the five spheres.

Layers of the atmosphere

- **Troposphere** (0–12 km) — contains most of the air and nearly all the water vapour; temperature falls with height; **all weather occurs here**.
- **Stratosphere** (12–50 km) — contains the **ozone layer**, which absorbs harmful ultraviolet radiation; aircraft fly in its lower part.
- **Mesosphere** — meteors burn up here.
- **Thermosphere and exosphere** — very thin air; auroras occur here; merges into space.

13.2 Energy from the Sun, albedo and the greenhouse effect

- The Sun is the ultimate source of energy for almost all processes on Earth.
- **Albedo** is the fraction of incoming solar radiation that a surface **reflects** back. Fresh snow and ice have a very high albedo (0.8–0.9); forests, ocean and dark soil have a low albedo (0.05–0.2).
- **Greenhouse effect:** short-wavelength solar radiation passes easily through the atmosphere and is absorbed by the Earth's surface. The warmed surface re-radiates energy as **long-wavelength infrared**, which is absorbed by greenhouse gases — CO₂, methane, water vapour, nitrous oxide — and re-emitted in all directions, including back down. This keeps the Earth warm.
- Without it, the average surface temperature would be about **–18 °C** instead of about **15 °C**, and liquid water and life would be impossible. The natural greenhouse effect is essential; the problem is its **enhancement** by human emissions, which produces global warming.
- **Uneven heating:** the Sun's rays fall vertically at the equator and obliquely near the poles, so the same energy is spread over a larger area at higher latitudes and passes through more atmosphere. This is the root cause of temperature differences, winds, ocean currents and climate zones.

Local winds

- **Valley breeze (daytime, upslope):** the mountain slopes heat faster than the valley floor and the air above them; the warm air over the slopes rises, and cooler air from the valley flows up to replace it.
- **Mountain breeze (night, downslope):** the slopes cool rapidly by radiation; the cold, dense air over them slides down into the valley.
- The same principle produces the **sea breeze** by day and the **land breeze** by night.

13.3 Biogeochemical cycles

A **biogeochemical cycle** is the circulation of an essential element between the living (biotic) and non-living (abiotic) parts of the Earth. Energy **flows through** the ecosystem and is lost as heat, but matter is **recycled** — the Earth's stock of carbon, nitrogen and water is fixed.

The water cycle

- Evaporation from oceans and water bodies, and transpiration from plants → condensation into clouds → precipitation as rain, snow or hail → run-off into rivers and infiltration into groundwater → return to the ocean.

The carbon cycle

- CO₂ is removed from the air by **photosynthesis** and by dissolving in the oceans.
- It is returned by **respiration** of plants and animals, by **decomposition** of dead matter, by **combustion** of fuels and by volcanic activity.
- Long-term storage: fossil fuels, limestone rock and the deep ocean.

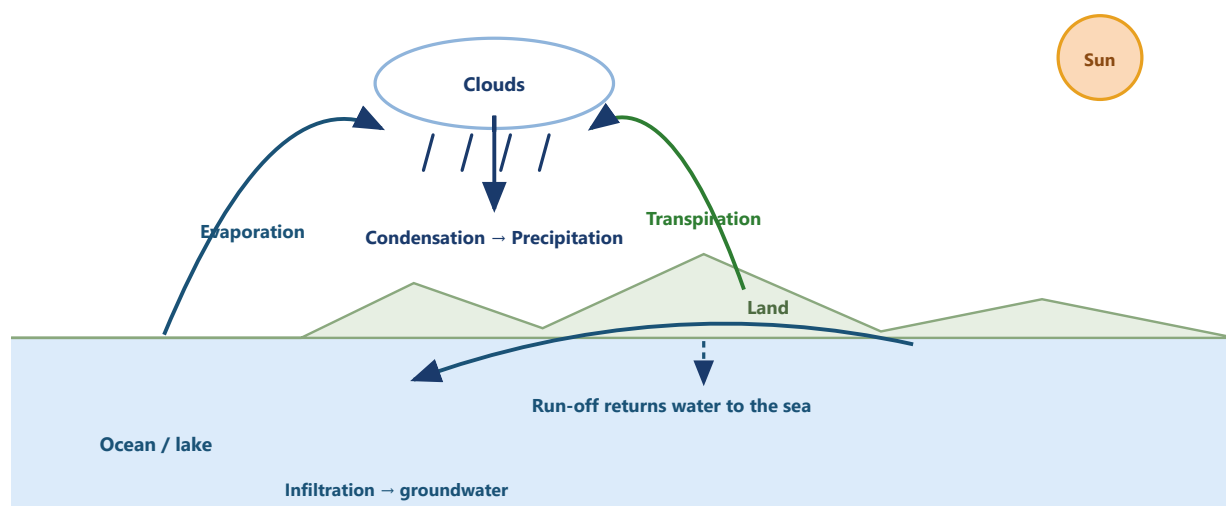


Fig. 13.C — The water cycle: evaporation, transpiration, condensation, precipitation and run-off

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

The nitrogen cycle

- **Nitrogen fixation** — atmospheric N₂ is converted to usable compounds by *Rhizobium* in the root nodules of legumes, by free-living soil bacteria, by lightning, and industrially by the Haber–Bosch process.
- **Assimilation** — plants absorb nitrates and build proteins and nucleic acids; animals get nitrogen by eating plants.
- **Ammonification** — decomposers convert the nitrogen of dead bodies and excreta into ammonia.
- **Nitrification** — nitrifying bacteria convert ammonia → nitrite → nitrate.
- **Denitrification** — denitrifying bacteria convert nitrates back to N₂, returning it to the atmosphere.

The oxygen cycle

- Oxygen is released by photosynthesis and consumed by respiration, combustion and the rusting of metals.

PART B — NCERT SOLUTIONS (REVISE, REFLECT, REFINE)

Q1

1 Mark

Choose the most appropriate option describing the role of biogeochemical cycles in an ecosystem.

(ii) To recycle essential nutrients between biotic and abiotic components

Q2

1 Mark

Which of the following is primarily responsible for the warming of the Earth?

(iii) The Earth's surface absorbs solar radiation, which is then re-radiated and trapped by greenhouse gases

Q3

3 Marks

Explain how climate change affects the water cycle. Illustrate with examples.

SOLUTION

- **Faster evaporation:** higher temperatures increase evaporation from oceans, lakes and soil, and increase transpiration from plants, so the whole cycle speeds up.
- **More water vapour in the air:** warmer air holds more moisture, which means heavier rainfall when it does rain — hence more cloudbursts and urban flooding, as seen increasingly in Indian cities during the monsoon.
- **Uneven distribution:** wet regions tend to get wetter and dry regions drier. Rainfall becomes concentrated in fewer, more intense events with longer dry spells in between.
- **Melting of the cryosphere:** Himalayan glaciers are retreating. Rivers such as the Ganga and Brahmaputra, which are glacier-fed, may carry more water in the short term and much less in the long term.
- **Rising sea level** from melting ice and the thermal expansion of sea water leads to the intrusion of salt water into coastal groundwater.
- **Shifting monsoon patterns:** warmer Arabian Sea temperatures are linked to erratic monsoon onset, more extreme rainfall days and more frequent droughts — directly affecting agriculture and drinking-water supply.

Describe how albedo affects the Earth's surface temperature and its climate.

SOLUTION

- **Albedo** is the proportion of incoming solar radiation reflected back by a surface.
- A **high-albedo** surface such as fresh snow or ice reflects 80–90% of the radiation, absorbs little, and therefore stays cold and keeps the air above it cold.
- A **low-albedo** surface such as the ocean, dark soil or a forest absorbs most of the radiation, warms up, and warms the air above it.
- Global average albedo therefore controls how much of the Sun's energy the Earth keeps — the higher the albedo, the cooler the planet.
- **The ice–albedo feedback** is the key climatic consequence: warming melts ice, exposing dark ocean or land of much lower albedo; more energy is absorbed; the warming increases; and still more ice melts. This positive feedback is why the Arctic is warming faster than the rest of the planet.
- **Human influence:** deforestation, urbanisation with dark roads and roofs, and soot deposited on snow all lower the albedo and add to warming; light-coloured roofs and preserved snow cover raise it.

How are mountain and valley breezes formed? If one mountain is grass-covered and another barren rock, would the temperatures of the two mountain breezes differ?

FORMATION OF THE BREEZES

- **Valley breeze (daytime, blowing upslope):** the Sun heats the mountain slopes strongly. The air in contact with them warms, becomes less dense and rises along the slope. Cooler, denser air from the valley floor flows up to take its place. This upslope wind is the valley breeze.
- **Mountain breeze (night, blowing downslope):** after sunset the slopes lose heat rapidly by radiation. The air above them cools, becomes denser than the air at the same height over the valley, and drains down the slope into the valley. This downslope wind is the mountain breeze.
- Both arise from the same cause — **differential heating and cooling** producing differences in air density and pressure.

GRASS-COVERED VERSUS BARREN ROCKY MOUNTAIN

- **Yes, the temperatures would differ.**
- Bare rock has a **low specific heat capacity** and no vegetation cover. It heats up strongly during the day and also **loses heat very rapidly** at night. The air above it cools sharply, so the mountain breeze from the rocky slope is **colder**.
- Grass cover insulates the ground, holds moisture and releases water vapour by transpiration. Moist air and vegetation moderate both heating and cooling, so the slope cools more slowly and the breeze from the grassy mountain is **warmer and more humid**.
- By day the situation reverses: the barren rocky slope becomes much hotter, so it generates a **stronger valley breeze** than the grass-covered one.

Which atmospheric layer is mainly responsible for winds, storms and rainfall, and what is the primary reason?

SOLUTION

- The layer is the **troposphere**, the lowest layer, extending to about 8–18 km depending on latitude.
- **Primary reasons:**
 - It contains almost all the **water vapour** and dust of the atmosphere, which are essential for cloud formation and precipitation.
 - It holds about **75% of the total mass** of the atmosphere.
 - Temperature **decreases with height** in this layer, and the layer is heated from below by the Earth's surface. This makes the air unstable, so warm air rises and cool air sinks, setting up strong **vertical convection currents**.
- This convection, combined with the uneven heating of land and sea, produces pressure differences, winds, cloud formation, thunderstorms and rainfall — all confined to this layer.
- Above it, in the stratosphere, temperature **increases** with height, which suppresses vertical mixing; that is why the stratosphere is stable and cloud-free, and why aircraft prefer to cruise there.

Explain the processes involved in the nitrogen cycle. How would life on Earth be affected if nitrogen were not cycled?

PROCESSES OF THE NITROGEN CYCLE

- **Nitrogen fixation** — atmospheric N_2 , which is chemically very unreactive, is converted into usable compounds:
 - biologically, by *Rhizobium* in the root nodules of leguminous plants and by free-living bacteria such as *Azotobacter*;
 - by **lightning**, which supplies enough energy to combine nitrogen and oxygen into oxides that dissolve in rain;
 - industrially, by the **Haber-Bosch process**, producing ammonia for fertilisers.
- **Assimilation** — plants absorb nitrates from the soil and use them to build proteins, nucleic acids and chlorophyll. Animals obtain their nitrogen by eating plants or other animals.
- **Ammonification** — decomposer bacteria and fungi break down dead organisms and excreta, releasing ammonia into the soil.
- **Nitrification** — nitrifying bacteria oxidise ammonia to nitrite and then to nitrate, the form plants can absorb.
- **Denitrification** — denitrifying bacteria in waterlogged soil convert nitrates back to free N_2 , returning it to the atmosphere and completing the cycle.

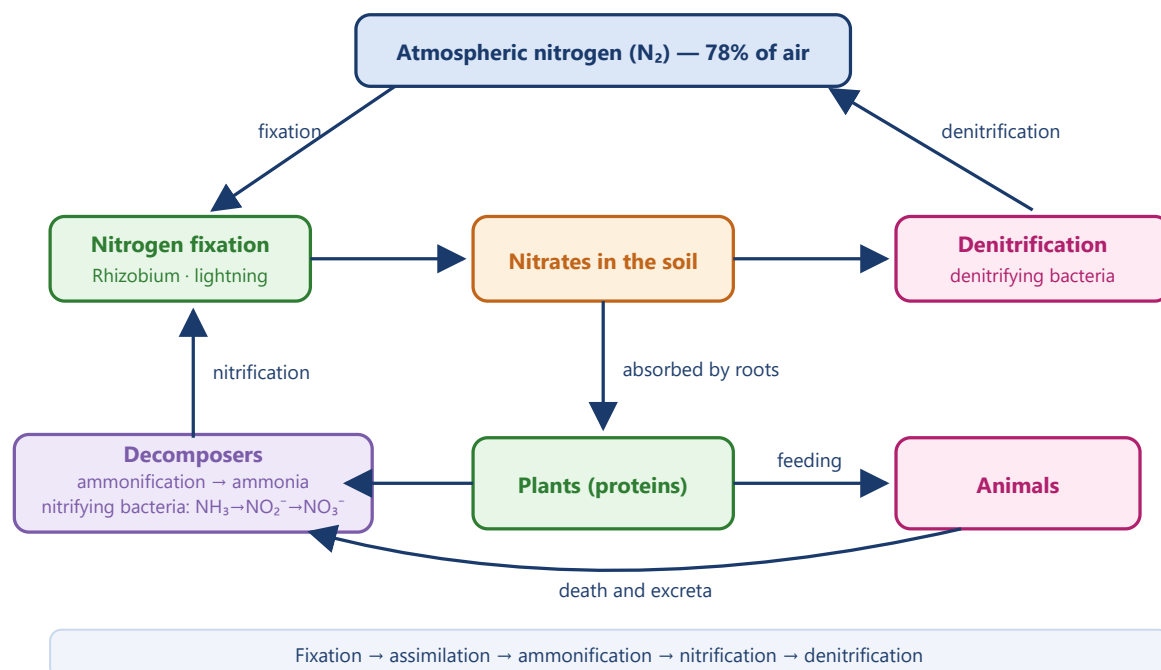


Fig. 13.A — The nitrogen cycle, fully labelled

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

- Nitrogen locked in dead bodies and excreta would never be returned to the soil, and the supply of usable nitrates would soon be exhausted.
- Plants could not make **proteins, nucleic acids or chlorophyll**, so growth would stop and photosynthesis would fail.
- Animals, which depend on plants for their nitrogen, would starve; food chains would collapse.
- Dead matter would accumulate without decomposing, and the atmospheric store of N_2 would become permanently unavailable — useless to life despite being 78% of the air.
- Life as we know it could not continue.

Q8

4 Marks

What are the impacts of deforestation on the Earth's oxygen and carbon cycles? What are its other consequences?

EFFECT ON THE OXYGEN CYCLE

- Trees are major producers of oxygen through photosynthesis. Removing them **reduces oxygen release** into the atmosphere.
- Burning the felled timber and the decay of the remains **consume further oxygen**.

EFFECT ON THE CARBON CYCLE

- Less photosynthesis means **less CO_2 is removed** from the atmosphere; forests are among the Earth's largest carbon sinks.
- The carbon stored in the trees over decades is **released as CO_2** when they are burnt or left to decay.
- The net result is a rise in atmospheric CO_2 , strengthening the greenhouse effect.

OTHER CONSEQUENCES

- **Soil erosion and loss of fertility** — roots no longer bind the soil, and topsoil is washed away.
- **Disturbed water cycle** — less transpiration means reduced local rainfall; run-off increases and groundwater recharge falls, causing floods in the wet season and drought later.
- **Loss of biodiversity** — destruction of habitat leads to extinction of species and to more human–wildlife conflict.
- **Desertification** of degraded land, and **lower albedo changes** altering local climate.
- **Loss of livelihood** for forest-dwelling communities, and loss of timber, medicines and other forest produce.

Explain with a suitable diagram the path that carbon takes to return to the atmosphere, starting from plants using CO_2 .

THE PATH, STEP BY STEP

- **1. Photosynthesis:** plants absorb CO_2 from the atmosphere and convert it into glucose and other organic compounds.
- **2. Feeding:** animals eat the plants, so the carbon passes along the food chain into animal tissue.
- **3. Respiration:** plants and animals oxidise glucose to release energy, giving back CO_2 to the atmosphere — the shortest return route.
- **4. Decomposition:** when plants and animals die, decomposer bacteria and fungi break down their bodies and release CO_2 during their own respiration.
- **5. Fossilisation and combustion:** some dead matter is buried and converted over millions of years into coal, petroleum and natural gas. Burning these fuels returns that carbon to the atmosphere as CO_2 — the route humans have accelerated enormously.
- **6. Other returns:** forest fires, volcanic eruptions, and the release of dissolved CO_2 from the oceans.

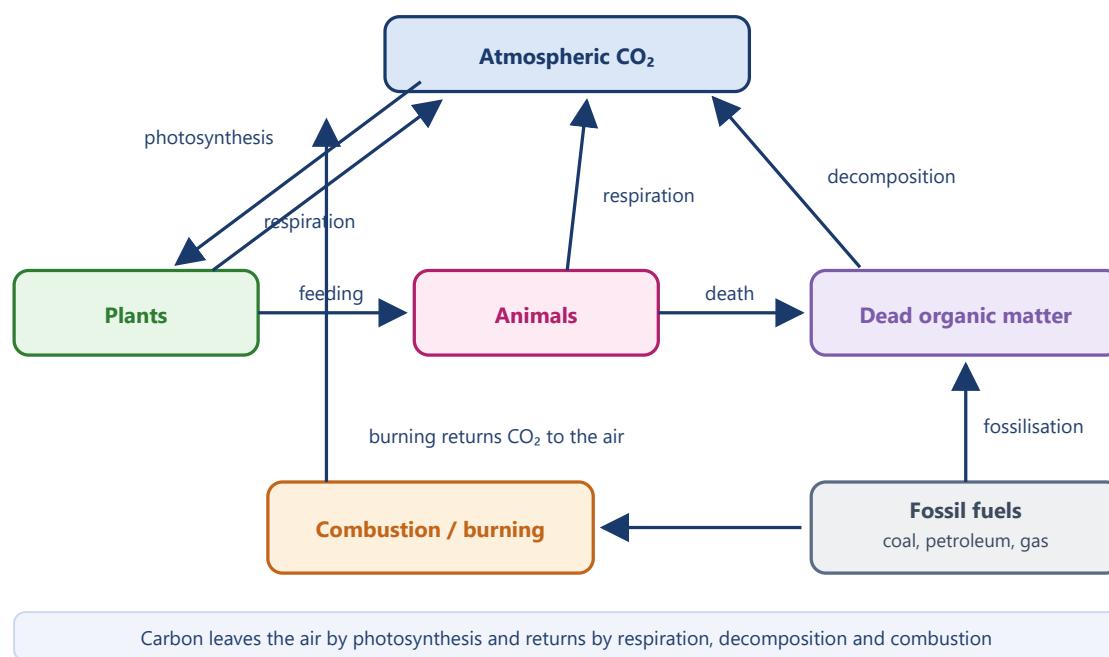


Fig. 13.B — Paths by which carbon returns to the atmosphere

If any part of this figure is not clear, students are kindly requested to refer to the corresponding figure in the NCERT textbook Exploration — Textbook of Science for Grade 9.

Q10**3 Marks**

Why is an excess of CO_2 in the atmosphere undesirable even though plants require it?

SOLUTION

- Plants need only a small concentration of CO_2 ; beyond a point their rate of photosynthesis is limited by light, water, temperature and minerals, so additional CO_2 gives no further benefit.
- Excess CO_2 strengthens the **greenhouse effect**, trapping more outgoing infrared radiation and causing **global warming**.
- This drives **climate change** — melting glaciers and polar ice, rising sea levels, erratic monsoons, more frequent droughts, floods and heat waves.
- A large part of the extra CO_2 dissolves in the sea, forming carbonic acid and causing **ocean acidification**, which damages corals and shell-forming organisms.
- Warming shifts the ranges of species, disturbs ecosystems and threatens agriculture and food security.
- The problem, in short, is not CO_2 itself but the **disturbance of the natural balance** of the carbon cycle by human activity.

Q11**3 Marks**

How is heat lost from the surface of the Earth? What is its significance?

HOW HEAT IS LOST

- **Radiation** — the warmed surface emits long-wavelength infrared radiation; part escapes to space and part is absorbed by greenhouse gases.
- **Conduction** — heat passes from the surface to the thin layer of air in direct contact with it.
- **Convection** — the warmed air rises and carries heat upward, being replaced by cooler air.
- **Evaporation (latent heat)** — water absorbs a large amount of heat in changing to vapour, carrying that energy upward until it is released on condensation.
- **Reflection** — a part of the incoming radiation never heats the surface at all, being reflected by clouds, ice and bright surfaces.

SIGNIFICANCE

- It maintains the Earth's **energy balance** — over the long run, energy lost must equal energy received, or the planet would heat up or cool down without limit.
- It keeps the surface temperature within the narrow range in which liquid water, and therefore life, can exist.
- The uneven loss of heat between the equator and the poles drives **winds, ocean currents and the whole weather system**.
- Evaporation and condensation in this process drive the **water cycle**.

If the Earth were a flat disc instead of a sphere, how would the patterns of solar radiation and temperature differ?

SOLUTION

- On a sphere, the Sun's rays strike **vertically at the equator and obliquely near the poles**. Oblique rays spread the same energy over a larger area and pass through a thicker layer of atmosphere, so the poles are cold and the tropics hot.
- On a **flat disc** facing the Sun, the rays would strike every part at **the same angle**. The energy received per unit area would be nearly uniform across the whole surface.
- Consequently there would be **no latitudinal temperature gradient** — no distinct tropical, temperate and polar zones, and no permanent polar ice caps.
- Since winds and ocean currents are driven by the temperature difference between equator and poles, global **wind belts and currents would largely disappear**, and with them the monsoon and much of the present weather.
- The disc would also have sharp edges and only one illuminated face, giving extreme and abrupt variations between the lit and unlit sides rather than the smooth day–night cycle of a rotating sphere.
- This thought experiment shows that the Earth's **spherical shape** is the fundamental cause of its climate zones.

Suppose there is a rise in atmospheric temperature on Earth. How would this affect the cryosphere, hydrosphere and biosphere?

CRYOSPHERE

- Glaciers, ice sheets, sea ice and snow cover would **melt and shrink**; permafrost would thaw, releasing stored methane and CO₂ and accelerating warming further.
- Loss of bright ice would **lower the albedo**, so still more solar energy would be absorbed — a positive feedback.

HYDROSPHERE

- **Sea level would rise**, both from the added meltwater and from the thermal expansion of warmer sea water, flooding low-lying coasts and islands.
- Evaporation would increase, speeding up the water cycle and making rainfall more erratic and more intense.
- Ocean temperatures would rise; dissolved oxygen would fall; ocean currents could be disrupted by the influx of fresh meltwater.
- Glacier-fed rivers would first swell and then dwindle, threatening water supply.

BIOSPHERE

- Species would **shift their ranges** towards the poles and to higher altitudes; those that cannot move or adapt, such as polar bears and alpine plants, would face extinction.
- **Coral bleaching** would increase with warmer, more acidic seas, damaging entire marine ecosystems.
- The **timing of biological events** — flowering, migration, breeding — would shift and fall out of step with the species each depends on.
- Crop yields would become unreliable, and vector-borne diseases such as malaria and dengue would spread to new areas.

The point to note is the **interconnection**: a change in the atmosphere alters the cryosphere, which alters the hydrosphere, which alters the biosphere — the defining feature of the Earth as a system.

Explain how the Earth's atmosphere helps in maintaining a suitable temperature for life.

SOLUTION

- **Greenhouse effect:** greenhouse gases such as CO_2 , water vapour and methane absorb the long-wavelength infrared radiation emitted by the warmed Earth and re-radiate part of it back. This keeps the average surface temperature near **15 °C** instead of about **−18 °C**.
- **Blanket against extremes:** the atmosphere prevents the surface from heating excessively by day and from losing all its heat at night, so the daily temperature range stays moderate. On the Moon, which has no atmosphere, the temperature swings from about +110 °C to −170 °C.
- **Shield against radiation:** the ozone layer of the stratosphere absorbs harmful ultraviolet rays, and the atmosphere burns up most incoming meteors.
- **Redistribution of heat:** winds and the resulting ocean currents carry heat from the equator towards the poles, evening out temperature differences.
- **Water cycle:** water vapour in the atmosphere absorbs and releases large amounts of latent heat, which further moderates temperature.

Describe the interrelationship between the different spheres of the Earth. Illustrate with an example how they function in a delicate balance.

THE INTERRELATIONSHIPS

- **Atmosphere ↔ Hydrosphere:** water evaporates from the oceans into the air and returns as rain; winds drive ocean currents; oceans absorb CO₂ and heat from the air.
- **Geosphere ↔ Hydrosphere:** rivers erode rock and deposit sediment; rain weathers rock and releases minerals; groundwater is stored in rock.
- **Biosphere ↔ Atmosphere:** plants take in CO₂ and release O₂; all organisms respire, returning CO₂; transpiration adds water vapour.
- **Biosphere ↔ Geosphere:** plants draw minerals from soil; decomposers return nutrients to it and help form soil from rock.
- **Cryosphere ↔ all others:** ice reflects solar radiation, controls sea level, stores fresh water, and supports specialised ecosystems.

EXAMPLE OF THE DELICATE BALANCE — DEFORESTATION IN A RIVER CATCHMENT

- Trees are cut down → the **biosphere** loses its producers.
- Less photosynthesis means more CO₂ stays in the **atmosphere**, strengthening the greenhouse effect; less transpiration reduces local rainfall.
- Without roots to bind it, topsoil of the **lithosphere** is washed away and fertility is lost.
- Run-off carries that silt into rivers of the **hydrosphere**, raising riverbeds, causing floods, and reducing groundwater recharge.
- Warming accelerates the melting of glaciers in the **cryosphere**, further altering river flow and sea level.
- The degraded land can support fewer organisms, so the **biosphere** is damaged again — the cycle closes.

Conclusion: a disturbance in any one sphere propagates through all the others. This is why environmental problems can never be solved by treating one sphere in isolation, and why the Earth must be studied as a single interconnected system.

PART C — EXTRA QUESTIONS (SOLVED)

All weather phenomena occur in the

(i) stratosphere (ii) troposphere (iii) mesosphere (iv) thermosphere

(ii) troposphere

E2

1 Mark

Which of these has the highest albedo?

(i) Ocean water (ii) Dense forest (iii) Fresh snow (iv) Black soil

(iii) Fresh snow

E3

1 Mark

Nitrogen fixation in the root nodules of leguminous plants is carried out by

(i) Rhizobium (ii) Nitrosomonas (iii) Pseudomonas (iv) Lactobacillus

(i) Rhizobium

E4

1 Mark

Assertion (A): The natural greenhouse effect is essential for life on Earth.

Reason (R): Without it the average surface temperature would be about -18°C and water would remain frozen.

(i) Both true, R explains A (ii) Both true, R does not explain A (iii) A true, R false (iv) A false, R true

(i) Both A and R are true, and R is the correct explanation of A

E5

2 Marks

Name the five spheres of the Earth and state what each consists of, in one line.

SOLUTION

- **Geosphere (lithosphere)** — the solid crust: rocks, soil and landforms.
- **Hydrosphere** — all water: oceans, rivers, lakes and groundwater.
- **Atmosphere** — the envelope of gases around the Earth.
- **Cryosphere** — all frozen water: glaciers, ice sheets, snow and permafrost.
- **Biosphere** — all living organisms and the zones they occupy.

E6

2 Marks

Why is energy said to flow through an ecosystem while matter is said to cycle?

SOLUTION

- Energy enters as sunlight, passes through the food chain, and is finally lost as heat to space — it cannot be reused, so it **flows in one direction**.
- The Earth's stock of carbon, nitrogen, oxygen and water is fixed; these elements are used, released and used again, so matter **circulates** between the biotic and abiotic components.

E7

2 Marks

Name any four greenhouse gases and one human activity that increases each.

SOLUTION

- **Carbon dioxide** — burning fossil fuels and deforestation.
- **Methane** — paddy fields, livestock, landfills.
- **Nitrous oxide** — excessive use of nitrogen fertilisers.
- **Chlorofluorocarbons** — older refrigerants and aerosol propellants.

E8

3 Marks

Explain the formation of a sea breeze and a land breeze with reference to differential heating.

SOLUTION

- **Sea breeze (daytime):** land heats faster than water because it has a lower specific heat capacity. The warm air over the land rises, creating low pressure, and cooler air from the sea moves in to take its place — a breeze from sea to land.
- **Land breeze (night):** land cools faster than the sea. Now the air over the sea is warmer and rises, and cooler air from the land flows out to replace it — a breeze from land to sea.
- Both arise from the same principle as valley and mountain breezes: **differential heating produces differences in air density and pressure**, and air moves from high to low pressure.

E9

3 Marks

Draw a flow outline of the water cycle and name the four main processes involved.

SOLUTION

- **Evaporation and transpiration** — water changes to vapour from oceans, rivers and the leaves of plants.
- **Condensation** — rising vapour cools and forms tiny droplets, producing clouds.
- **Precipitation** — droplets combine and fall as rain, snow or hail.
- **Collection and run-off** — water gathers in rivers, lakes and oceans, or infiltrates the ground to become groundwater, and the cycle begins again.

Ocean → Evaporation → Condensation (clouds) → Precipitation → Run-off / infiltration → Ocean

E10**3 Marks**

Why do farmers grow leguminous crops such as gram or moong in rotation with cereals?

SOLUTION

- Cereals such as wheat and rice take large amounts of nitrogen from the soil and give none back, so soil nitrogen falls steadily.
- Leguminous plants have **Rhizobium bacteria in their root nodules**, which fix atmospheric nitrogen into compounds the plant can use.
- When the roots and crop residues decay, this nitrogen enters the soil and **restores its fertility naturally**, reducing the need for chemical fertilisers and lowering cost and pollution.

E11**4 Marks**

Case study: A city replaces a large park with concrete buildings and asphalt roads. Residents report that summer nights have become noticeably hotter than in nearby villages. (i) Name the phenomenon. (ii) Explain it in terms of albedo and heat capacity. (iii) Which sphere interactions are involved? (iv) Suggest two remedies.

SOLUTION

- (i) The **urban heat island** effect.
- (ii) Concrete and asphalt are dark, with a **low albedo**, so they absorb far more solar radiation than the vegetation they replaced. They also have a high heat capacity and store that heat through the day, releasing it slowly at night, which keeps the city warm after sunset. Removing the park also removes **transpiration**, which previously cooled the air by absorbing latent heat, and removes shade.
- (iii) The **biosphere** (loss of vegetation) affects the **lithosphere** (surface replaced by built material), which affects the **atmosphere** (higher air temperature) and the **hydrosphere** (less transpiration, more run-off, less groundwater recharge).
- (iv) **Remedies:** plant trees and create green belts, parks and rooftop gardens; use light-coloured or reflective roofs and paving to raise the albedo; and keep permeable surfaces and water bodies within the city.

What is global warming? State any three causes, three effects, and three measures to reduce it.

DEFINITION

- **Global warming** is the gradual rise in the average temperature of the Earth's atmosphere and oceans, caused mainly by the increased concentration of greenhouse gases due to human activity.

CAUSES

- Burning of fossil fuels in vehicles, industry and power stations, releasing CO₂.
- Deforestation, which removes the carbon sinks that absorb CO₂.
- Methane from paddy fields, livestock and landfills; nitrous oxide from heavy fertiliser use.

EFFECTS

- Melting glaciers and polar ice, and a rising sea level that threatens coastal cities.
- Erratic monsoons, more frequent droughts, floods, heat waves and cyclones.
- Loss of biodiversity, coral bleaching, ocean acidification and falling crop yields.

MEASURES

- Shift to renewable sources — solar, wind and hydro — and improve energy efficiency.
- Afforestation and protection of existing forests; use public transport, cycling and electric vehicles.
- Reduce, reuse and recycle to cut waste and emissions; manage fertiliser use; support international agreements on emission control.

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