Exploration

Textbook of Science for Grade 9

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NCERT

राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

0906 – Exploration
Textbook of Science for Grade 9

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Foreword

The National Education Policy (NEP) 2020 envisions an education system that is firmly rooted in India's cultural and intellectual wisdom, values, and ethical traditions. The rich intellectual heritage simultaneously enables learners to engage meaningfully with the complexities and possibilities of a rapidly changing world. The National Curriculum Framework for School Education (NCF-SE) 2023 provides concrete expression to this vision by laying out a coherent curricular pathway across various stages of schooling that nurtures critical thinking, creativity and sensitivity, along with the values and dispositions that are needed for responsible citizenship in an interconnected global society.

Learners have progressed through the foundational, preparatory and middle stages, where their inherent potential has been nurtured holistically. Now, they enter the secondary stage with enhanced capacity for reflection, reasoning, enquiry, and self-expression. Spanning across Grades 9 to 12, also known as the adolescent stage, it marks a crucial period in the intellectual and personal growth of the students. It prepares them to engage with abstract ideas, complex social realities, ethical dilemmas and the expanding universe of knowledge, while deepening their understanding of the self and the world around them.

The NCF-SE 2023 recommends that the curriculum for Grades 9–10 equips students with the skills that are needed to grow as they advance in their lives. Students can use these skills for reasoning, argumentation, and effective communication. It endeavours to enhance their analytical and descriptive capabilities to prepare them for the challenges and opportunities that await them. A diverse curriculum, covering ten subjects; three languages—including at least two languages native to India, Science, Mathematics, Social Science, Art Education, Physical Education and Well-being, Individuals in Society or Environmental Education, and Vocational Education promotes their holistic development.

As per the NCF-SE 2023, science education at this stage aims to develop scientific temper, critical thinking, and problem-solving skills. It emphasises connecting scientific concepts to everyday life enabling students to understand and apply knowledge meaningfully. The framework promotes inquiry-based learning, environmental awareness, and values, such as curiosity, objectivity, and respect for evidence making science learning engaging, relevant, and learner-centred.

Exploration, the textbook of science for Grade 9, aligns with the NEP 2020 and the NCF-SE 2023 by promoting experiential and inquiry-based learning. It encourages students to ask questions, make predictions, analyse information, and draw logical conclusions. The textbook presents science as an evolving body of knowledge shaped by collective effort and continuous refinement. By integrating concepts from physics, chemistry, biology, and earth science, it fosters a holistic understanding of science, and highlights the interrelationship between science, technology and society.

Through hands-on activities, real-life examples, and collaborative learning experiences, the textbook strengthens creativity, logical reasoning, and decision-making skills. It nurtures curiosity, cooperation, respect for life, and concern for the environment. While *Exploration* serves as a central learning resource, it also invites students to engage with a broader world of books, media, digital archives, libraries, and community knowledge. The role of teachers, parents, and school libraries is, therefore, pivotal in nurturing a rich culture of reading, dialogue, and independent exploration at this stage. The textbook integrates technology through the use of QR codes in each unit, which provide additional reading material and resources.

The National Council of Educational Research and Training acknowledges the contributions of the Textbook Development Team, subject experts, pedagogues, practising teachers, reviewers, and all others who have supported the development of this textbook. We hope *Exploration* inspires learners to think critically, communicate with confidence, and participate thoughtfully in the intellectual and social life of our nation and the world. We welcome suggestions and feedback from all its users for further improvement in the subsequent editions.

Dinesh Prasad Saklani
Director
National Council of Educational
Research and Training

New Delhi
February 2026

About this Book

You may have enjoyed learning science through your textbooks *Curiosity* during the middle stage. You may have realised that science is not just about answers; it begins with questions. This indicates that you have begun to develop an interest in learning and exploring science. As you continue this journey, this ongoing cycle of questioning and discovery becomes a natural part of how you grow and understand the world. By the end of Grade 8, you would have successfully developed all the competencies outlined in the NCF-SE 2023 for the middle stage.

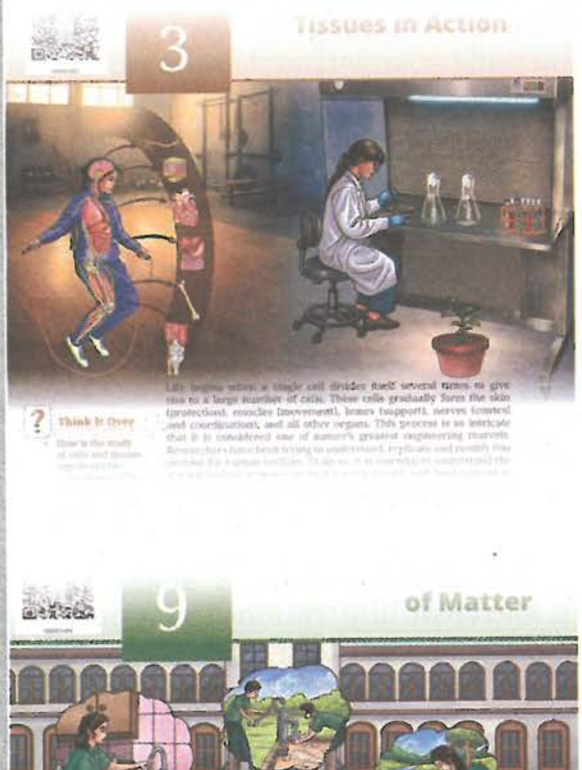
Building on this strong foundation, the Grade 9 science textbook has been developed in alignment with the NEP 2020 and the NCF-SE 2023 to support a deep understanding and sustained interest in science. *Exploration*, the title of the science textbook for Grade 9, means investigating the unknown by observing, posing questions, and experimenting to understand and discover the world around us. This textbook is designed to help you learn topics related to the world of matter, its interactions and properties at the atomic level; the physical world, and the scientific principles and laws that govern it; the structure and function of the living world at the cellular level, and the interconnectedness between organisms and their environment.

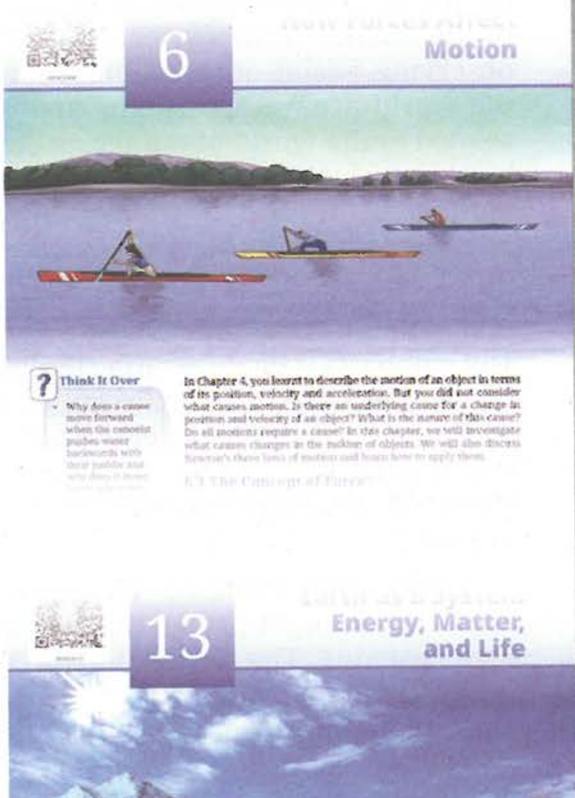
The main aim of the science textbook, *Exploration*, is to engage you in understanding the processes of science and discovering new information. The emphasis is on integrating topics from biology, chemistry, physics, earth science, and other curricular areas, such as environmental education, value education, and inclusive education. The goal is to help you learn through real experiences and not by simply memorising facts. After going through this book, we hope you will become a responsible and sensitive member of society.

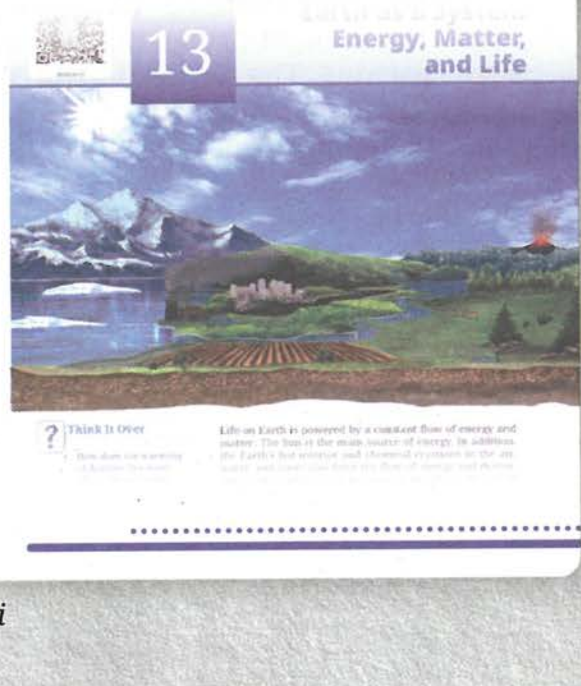
Exploration contains 13 chapters. Each chapter includes engaging activities, thought-provoking questions, and clear illustrations to support your learning. The design, layout, and cover page visually communicate curiosity, exploration, and the nature of science. It provides a visual overview of the scientific concepts that may be covered in the textbook. The first chapter, 'Exploration: Entering the World of Secondary Science', provides guidance on examining scientific concepts more closely and carefully. It makes you aware of scientific language, scientific ideas, and their appropriate use for clear, unambiguous communication. It also helps to understand the world around us more systematically through experimentation. This chapter encourages you to appreciate how science connects naturally with mathematics, technology, arts, and social sciences. It motivates you to ask focused questions, design and try out simple experiments to help answer them, and use your observation, exploration, and investigation skills to understand that Science is not merely a subject, but a way of looking at the world. This chapter provides a friendly introduction to your science journey at the secondary stage.

The page numbers of the textbook have been thoughtfully designed, framed by a **magnifying glass** and a **compass**. What might these symbols represent? Try to guess—but their meaning will be revealed in the first chapter.

Each chapter begins with a **thought-provoking image** related to the title of the chapter, designed to capture your attention and connect the scientific concepts you learn with everyday life. It encourages you to think, explore, and uncover its meaning as you read.







Think It Over

Each chapter includes a few **Think It Over** questions that encourage you to reflect deeply and explore new ideas. Some of these questions are open-ended and thought-provoking, often framed as why, what, or how questions, to promote critical thinking and curiosity. You may not find immediate answers to all of them, but do not worry; you will be able to explore these questions as you progress through the chapter. These questions help deepen your curiosity and provide insight into the process of science. In fact, several questions may arise in your mind and we hope that you may find answers as you go through the chapters.

Let us take a look at the approach used in this textbook. It is activity-based. These activities are designed to reflect how science works, offering both intellectual and hands-on experiences. They promote teamwork and are inclusive. You are expected to explore concepts by performing activities and seeking guidance from teachers, especially during experiments involving heating devices, corrosive chemicals, microscopes, and similar equipments. In some activities, **Safety first** or precautions are provided to ensure you work safely, particularly when using flammable, corrosive, hot, sharp, or breakable materials. These precautions help prevent accidents, ensuring that everyone can enjoy the activities while learning safely. Teachers are expected to pay special attention while supporting children with special needs and to encourage peer interaction. **Notes** are added at various places to provide additional information, explorations, or clarifications without interrupting the main text. They may help you better understand the content.

Grade 8
Curiosity
Chapter 8

At various places in the text, you may find **Grade of the textbook**, **Name of the textbook**, **Chapter number** as an icon, which helps you remember what you already know and link it to new concepts.

Next Level Up

Next Level Up will make you aware that there is still more to know about the topic, which you will learn in higher grades. Several concepts bridge science with other subjects and these interconnections can be explored by accessing the textbooks of different subjects through the provided website link: *https://ncert.nic.in/textbook.php*

Pause and Ponder

Questions are provided after each section or sub-section for self-assessment. These questions help you assess your understanding and reflect how much you have learnt. Many of them encourage critical thinking, reflection on your own ideas, and critical analysis of concepts. In addition, solved numerical examples are included wherever necessary to clarify concepts.

Threads of Curiosity

Some challenging ideas, additional information, interesting facts, and other enriching content are featured in boxes labelled **Threads of Curiosity**. These boxes are designed to encourage curiosity through interesting observations, thought-provoking questions, and fascinating insights.

Ready to Go Beyond

These boxes contain advanced concepts that explore the topic in more depth. The information in these boxes also applies scientific principles and knowledge to real-world contexts, showing how science has contributed to societal development. The intention is to present you with an opportunity to think and explore somewhat beyond the text, and you may feel the urge to continue your scientific expedition at higher levels.

Bridging Science and Society

Bridging Science and Society highlights how science has helped solve real-world problems. This includes improving health, protecting the environment, advancing technology, and enhancing the overall quality of life. By understanding these, you may learn how scientific concepts can be used to become responsible and informed citizens.

India's Scientific Contributions

It traces how individuals and institutions have nurtured scientific temper, showcasing achievements that have shaped society from ancient times to the present.

Think as a Scientist

In most of the chapters, you will find **Think as a Scientist** boxes, where you can explore the experiment further by making modifications or trying different approaches. It will help you investigate more deeply and allow new questions to emerge. These boxes connect theory with real-world applications by using models to make complex ideas easier to understand.

Meet a Scientist

The chapters also feature a section called **Meet a Scientist**, where you can learn about the contributions of Indian and international scientists related to the topic. These sections include brief biographies and show how scientists have made a difference. Additionally, an interesting element incorporated in some chapters is the introduction of striking examples from Indian contexts to promote rootedness among learners, as envisaged in the NEP 2020.

What if ...

It presents hypothetical situations or open-ended questions, which may encourage you to think creatively and apply scientific concepts to new situations. Such questions may also involve ethical issues, helping you reflect on the social responsibility and values associated with scientific developments.

The Quest Continues ...

It highlights unanswered questions where current scientific understanding is still being explored. It will give you an idea that science is an ongoing process, and that scientists are still actively exploring and seeking answers to these questions.

At a Glance

This section provides a summary of the chapter, offering an overview of its main points and reinforcing the key ideas discussed.

Each chapter also includes ***Keywords*** embedded within the text that highlight important concepts, helping you understand ideas clearly and think critically. These keywords also outline procedures used in scientific activities.

Revise, Reflect, Refine

The exercises at the end of each chapter, titled **Revise, Reflect, Refine**, include a variety of questions of different forms and formats, offering a challenging and engaging learning experience. These questions also help to assess the competencies learners developed in each chapter. Teachers are encouraged to use questions similar to those in this section for evaluation purposes.

The Journey Beyond

A key feature of the book is **The Journey Beyond**, which includes activities and projects designed to encourage positive interaction with classmates, experts, teachers, parents, and the community. These activities motivate you to gather information from diverse sources and draw your own conclusions. This approach makes science more interesting, challenging, meaningful, and closely connected to real life. Some activities and projects may require prior preparation.

The last page (epilogue), **Ready for New Horizons?** revisits key ideas and looks ahead to the exciting science of Grade 10.

Special care has been taken to simplify the language without losing the rigour of science, so that the concepts can be understood easily. The textbook is one way to learn, but you should also explore and observe your surroundings. Information and Communication Technology (ICT) can further enhance learning when used appropriately. Quick Response (QR) codes and hyperlinks in the textbook provide access to interactive resources allowing learners to explore at their own pace.

How to stay safe while exploring and gathering information from the internet?

- Use strong passwords that include letters, numbers, and symbols.
- Never share your passwords with anyone, not even friends.
- Avoid clicking on unknown links and pop-up advertisements.
- Do not download applications or files from unknown or untrusted websites.
- Never share personal details, such as your phone number or address.
- Always log out after using email or other online accounts.
- Inform your teacher or a trusted elder in your family if you come across anything online that makes you feel unsafe.

These steps help you stay **safe**.

Protect your information online!

Friends! Science is full of wonders and there is always more to explore. That is why *Exploration* motivates you to keep searching, investigating, and discovering new ideas and knowledge.

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CONSTITUTION OF INDIA

Part III (Articles 12 – 35)
(Subject to certain conditions, some exceptions
and reasonable restrictions)
guarantees these

Fundamental Rights

Right to Equality

- before law and equal protection of laws;
- irrespective of religion, race, caste, sex or place of birth;
- of opportunity in public employment;
- by abolition of untouchability and titles.

Right to Freedom

- of expression, assembly, association, movement, residence and profession;
- of certain protections in respect of conviction for offences;
- of protection of life and personal liberty;
- of free and compulsory education for children between the age of six and fourteen years;
- of protection against arrest and detention in certain cases.

Right against Exploitation

- for prohibition of traffic in human beings and forced labour;
- for prohibition of employment of children in hazardous jobs.

Right to Freedom of Religion

- freedom of conscience and free profession, practice and propagation of religion;
- freedom to manage religious affairs;
- freedom as to payment of taxes for promotion of any particular religion;
- freedom as to attendance at religious instruction or religious worship in certain educational institutions.

Cultural and Educational Rights

- for protection of interests of minorities;
- for minorities to establish and administer educational institutions;
- saving of certain Laws 31A–31D.

Right to Constitutional Remedies

- by issuance of directions or orders or writs by the Supreme Court and High Courts for enforcement of these Fundamental Rights.

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THE CONSTITUTION OF INDIA

PREAMBLE

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a [1][**SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC**] and to secure to all its citizens :

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith and worship;

EQUALITY of status and of opportunity; and to promote among them all

FRATERNITY assuring the dignity of the individual and the [2][unity and integrity of the Nation];

IN OUR CONSTITUENT ASSEMBLY this twenty-sixth day of November, 1949 do **HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.**

1. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Sovereign Democratic Republic" (w.e.f. 3.1.1977)
2. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Unity of the Nation" (w.e.f. 3.1.1977)

Exploration: Entering the World of Secondary Science

Chapter 1

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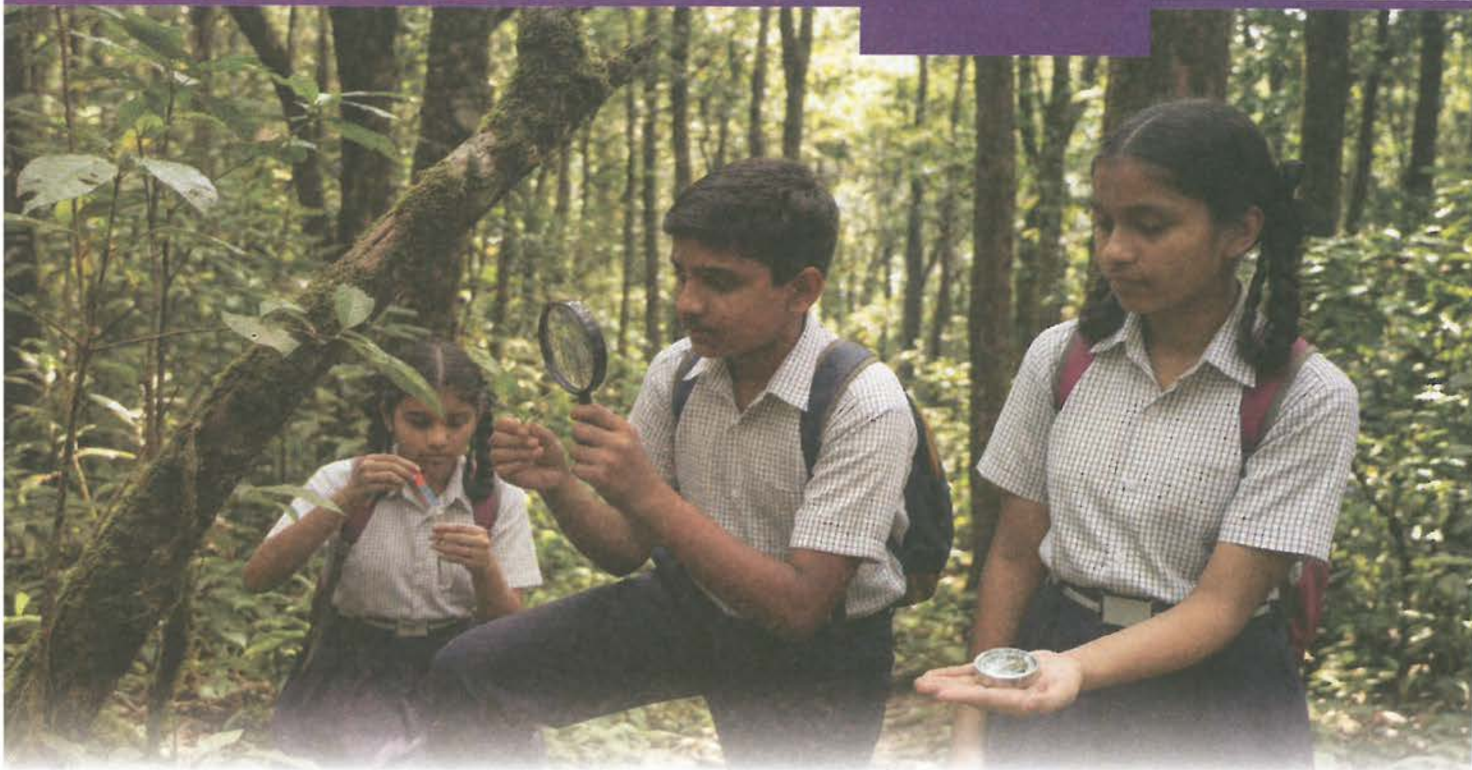


In the middle stage, science invited you to be curious and observe the world closely, to ask questions, and to find out how things work. In our journey, we discovered that science began with wonder and grew through careful experiments. We connected ideas across the world of the living and non-living. As you now enter the secondary stage, this journey continues, but with an emphasis on deep exploration. Science is not only about what we know, but also about how we know it — how observations lead to measurements, how patterns are expressed using symbols and equations, how models are built to represent complex systems, and how ideas are tested, often revised, and sometimes even discarded. In our secondary stage, textbook of science, ***Exploration***, we will look more closely, think more carefully, and find out how scientific ideas help us make sense of nature, technology and our place within them.

To reflect the approach of this textbook, the page numbers have been thoughtfully designed, and are framed by a magnifying glass and a compass. The magnifying glass symbolises careful observation — noticing patterns and paying attention to what might otherwise be missed. The compass reminds us that exploration also needs direction — choosing appropriate models, asking the right questions, and knowing the limits of where our ideas apply. Together, they tell us that exploration in science is not wandering aimlessly, but trying to make sense of our world with care and purpose.

The natural world is complex, and studying it in full detail is often impossible. To make sense of this complexity, science uses models. These are simplified ways of looking at real systems that focus only on what is most important for a given question. In physics, a moving car may be represented as a single point, while in chemistry, atoms and molecules are drawn as spheres and bonds. In biology, cells are shown as diagrams highlighting key parts, and in earth science, the Earth may be treated as a smooth sphere layered into distinct regions. Building such models involves *making assumptions and deliberately ignoring certain details*. For example, when studying the motion of a falling object, air resistance may be neglected to understand the basic effect of gravity. In biology, when studying how the heart pumps blood, many individual cells are ignored so that the organ can be understood as a functioning system. Remember that these choices are not mistakes, they are done on purpose to keep things simple enough, but still allow us to find answers to what we are looking for.

Meet a Scientist

Meghnad Saha on an Indian postage stamp

Simplifying the stars: Science often begins by ignoring details. When physicist **Meghnad Saha** studied the light from stars, he did not try to model every atom, every reaction, or every movement inside a star. Instead, he treated the matter in the star as a hot gas, ignored many complex processes, and focused only on temperature, pressure, and how atoms formed ions. This simplification allowed him to explain how the colour of stars is deeply connected to their temperature.

Example 1.1: 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?

Answer: We must ask, "Will the ball cross the boundary without hitting the ground first?". For this, things like the brand of the bat, the colour of the ball, the amount of grass on the field will make no difference. On the other hand, the mass of the ball, and the speed and direction in which it has been hit will be very important. Air resistance, the spin of the ball, and the stitching of the threads at the seam have smaller effects that can be ignored in a simple model. As we build more and more complex models, we add extra details for greater accuracy.

Activity 1.1: Let us model

Suppose you ride a bicycle from your school to your home. You want to model the time it takes to go home from school. What details would you keep? What details could you ignore? Suggest why ignoring some details may actually be useful.

As you explore science more deeply, you will notice that it uses language in a very careful and precise way. Many words that we use in everyday life, such as force, work, cell, or reaction have specific meanings in science. These meanings are often very specific because scientific ideas must be communicated clearly and unambiguously. To allow scientists across the world to describe observations, compare results, and build ideas together, science uses a shared language of these specific terms, symbols, and units. Quantities, such as mass, velocity, force, and electric current are represented by **symbols** like m, v, F, and I each associated with a defined unit.

To make this even more precise, science often turns to mathematics to allow relationships between quantities to be expressed clearly and tested carefully. This can sometimes feel challenging, but it is important to remember that mathematics in science is not meant to be a hurdle. Instead, 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 certain things are related. For example, describing motion using quantities, such as distance, time, and velocity allows us to answer questions about where an object will be at a later moment. In the same way, mathematical expressions are used to describe rates of chemical reactions, patterns of population growth, or changes in energy within a system. Learning to use mathematics in science does not mean memorising equations. It means understanding the situation first, identifying relevant quantities, and then using mathematical relationships to reason carefully. In this way, mathematics becomes a powerful language for thinking, not just for finding numerical answers. If you focus first on understanding the situation and the quantities involved, equations will begin to feel less like obstacles and more like helpful guides in your exploration of science.

Threads of Curiosity

Why is the speed of light denoted by 'c'?

Scientific symbols often come from history, and are based on international agreements, not necessarily abbreviations of convenience. For example, the speed of light, is usually denoted with the symbol c, since it comes from the Latin word *celeritas*, meaning speed. Today, the speed of light is one of the physical constants, defined to be exactly 299792458 m/s.

Ready to Go Beyond

Airplane fuel miscalculation

In a well-known incident, a passenger aircraft ran out of fuel mid-flight due to a mix-up in units. The flight needed 22,300 kg fuel in total, but the ground crew miscalculated the fuel required, since they used the density of fuel in pounds (lb) per litre rather than kilograms (kg) per litre. The aircraft was about 15,000 litres short of fuel and luckily could glide to an emergency landing, which damaged the aircraft though there were no casualties. Pounds and kilograms are very different. Using standard units (SI) everywhere avoids conversions and errors.

Threads of Curiosity

Why is a kilogram used everywhere?

When we buy rice or vegetables we expect a kilogram to mean the same amount everywhere (Fig. 1.1). Imagine the confusion if we used different weights everywhere! Thankfully, measurements are based on agreed international standards, not local objects or opinions. Standard units allow scientific results to be compared, and ensure fairness in daily life and trade.

Fig. 1.1: A vegetable seller using a pan balance

As observations are repeated, measurements refined, and ideas tested through experiments we can organise our understanding of the world in a systematic way. In the secondary stage, you will come across terms, such as laws, theories, and principles — terms that have specific meaning in science. A **law** usually describes a regular pattern observed in nature, often expressed using words or mathematical relationships. For example, Newton's laws of motion explain the jerk felt when a bus stops suddenly.

A **theory** goes a step further and provides an explanation of why those patterns occur, usually based on evidence gathered over time and available at that time. For example, the atomic theory explains how molecules are formed. **Principles** are broad ideas that help us make sense in a given situation. For example, the principle of conservation of energy being applied when climbing up the stairs.

Do remember that in science, a theory does not mean a guess or an untested idea, it is an explanation based on careful testing and critical examination. These ideas are always open to improvement and often change as new evidence becomes available. This is a key feature of science that makes it reliable.

One of the most remarkable strengths of science is its ability to make **predictions**. When laws, theories, and models are well established they allow us to anticipate what will happen under new or different conditions, before we can perform an experiment, and in many cases even if we cannot perform an experiment. Using ideas about motion, we can predict how far a kicked football will travel; using knowledge of chemical reactions, we can estimate how much carbon dioxide will be produced, or how soft a baked bread would be; using biological principles, we can predict how one's breathing would change while running. Remember that 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. But even more important, when they do not, scientists re-examine their assumptions, models, or measurements. In this way, prediction is a powerful tool that drives further exploration and a deeper understanding of the world.

Pause and Ponder

1. 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?

Example 1.2: How do we check predictions? Varsha told her friend Meghna, "It will rain this afternoon because the clouds look dark". Think of some questions Meghna could ask Varsha to make this prediction scientifically testable.

Answer: Good scientific questions will look for measurable evidence and past patterns. Questions with simple yes/no answers are usually not so useful. Meghna could ask Varsha questions like (these are just examples) "What was the condition of sky when it rained the last time? 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 like it did before the recent rains?". Questions like these ask about measurable data and past patterns, which go beyond mere 'clouds look dark'.

Ready to Go Beyond

Why do weather forecasts sometimes go wrong?

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

Even the most successful scientific theories have limits and may fail when new conditions are explored or when measurements become more precise. Such failures are not a weakness of science; in fact, they are its greatest strength. When predictions do not match observations, scientists do not reject ideas based on opinion or belief, but only on evidence. No scientific theory is ever final and none is beyond question. This openness to being corrected by nature itself is what has allowed science to help us in understanding the world we live in.

Threads of Curiosity

Checking 'viral' claims on social media: Is eating food harmful during an eclipse?

A commonly circulated claim is that, "Food should not be eaten during an eclipse because it becomes harmful". Disproof comes from asking simple scientific questions. An eclipse is just a play of shadows (Fig. 1.2). What physical change occurs during an eclipse? Does temperature change significantly? Does food go bad if it is left in a shadow? You will conclude that no physical, chemical, or biological mechanism supports such a claim.

Fig. 1.2: A total solar eclipse

As you continue your journey through science in Grades 9 and 10, you will gradually develop habits of thinking that are useful far beyond the classroom. A helpful strategy is to first understand the situation being studied, 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. Often, an approximate estimate is enough to tell us 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?

To make a rough estimate, assume that all their calorie needs come from rice alone (Fig. 1.3). An average adult needs about 2000 – 2500 kilocalories (kcal) per day. Find out how many calories 100 g of uncooked rice provides when cooked and use this to estimate the daily requirement for the family. The aim is not to get an exact number, but to check whether the answer makes sense as 100 g for a month is clearly too little, while a few tonnes is far too much. Such estimation helps connect science to everyday questions about food and resources, and shows why approximate reasoning is an important scientific skill.

Fig. 1.3: Rice being cooked on a gas stove

Example 1.3: 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. Your aim is not to find an exact answer, but a reasonable estimate.

Answer: At rest, we take about 12 – 15 breaths a minute, and there are $60 \times 24 = 1440$ minutes in a day, so we take roughly 18 – 22 thousand breaths, about 20 thousand breaths a day. We also need to find the volume of air in one breath. One way to estimate this is to think that it takes about 4 – 5 breaths to fill a typical rubber party balloon, which when inflated has a volume of about 2 litres. So, one breath is perhaps about 0.5 litre. Hence, we breathe in about 10,000 litres of air a day!

Now, it is hard to see if this estimate is reasonable or not. But if we go back to our balloon example, one could blow up a balloon in about 20 s, so maybe we could fill 3 balloons a minute. Multiplying $\frac{3\text{ balloon}}{\text{minute}} \times \frac{2\text{ litres}}{\text{balloon}} \times \frac{1440\text{ minutes}}{\text{day}}$ will give about 8640 litres, which for estimation purposes is reasonably close to our earlier estimate of 10,000 litres. Naturally, we would get extremely tired very quickly after blowing balloons nonstop, unlike normal restful breathing.

Pause and Ponder

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

After Grade 10, if you decide to study science, it will be divided into branches like physics, chemistry, biology and earth science, and even in Grades 9 and 10, the chapters you have will focus on some of these areas. We've highlighted some of the exciting things you may learn about in the Next Level Up boxes. However, do remember that the natural world does not have any such boundaries. These divisions are made by us to only help organise knowledge, they are not independent of each other. Most of the real-world problems today, such as understanding climate change, developing medicines, or designing sustainable technologies require ideas from several disciplines together. Science also connects naturally with mathematics, technology, arts, and social sciences. To make sense of the world fully, we need to connect multiple ways of knowing and expressing ideas, each enriching the other.

Pause and Ponder

3. Choose a real-life object (maybe a pressure cooker or a mobile phone) or a problem (maybe a traffic jam near your school). Make a sketch listing what kind of ideas from physics, chemistry, biology, earth science, or mathematics are involved. Show how at least two branches of science connect with your example.

Ready to Go Beyond

How does a mask really work?

Solving real problems requires knowledge from several branches of science. During the COVID-19 pandemic, we all used masks for safety (Fig. 1.4). Understanding how a mask works requires concepts from physics (particle motion and electrostatic attraction), chemistry (properties of polymer fibres), biology (size and behaviour of viruses), and mathematics (modelling airflow and filtration efficiency).

Fig. 1.4: A collection of surgical masks

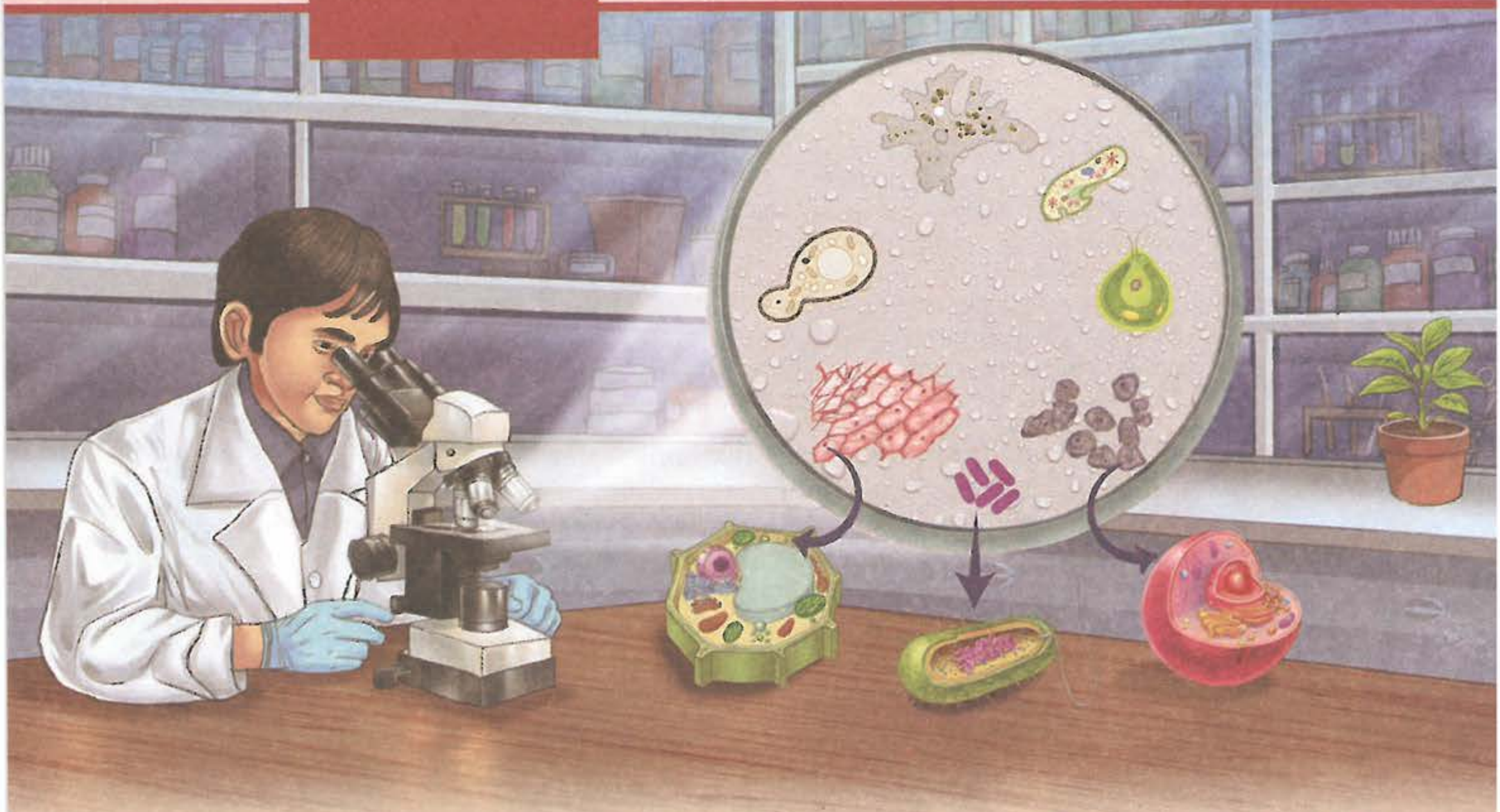
Finally, as we have mentioned in every textbook, science is not just a collection of facts, equations, or experiments. It is a human activity shaped by curiosity, creativity, collaboration, and careful questioning. It grows as people ask questions, test ideas, share results, and learn from mistakes. Science develops over time through the work of many individuals across different cultures and generations. Even if you do not choose to study science beyond Grade 10, scientific thinking will be very important in whatever you do. It helps you understand the technology that surrounds you, and helps you evaluate information critically and make sense of the world you live in. As you begin this stage of exploration, science invites you not only to learn about the world, but also to learn 'how' we are trying to understand it.

Embark on your journey of discovery — looking carefully through the magnifying glass of evidence and guided by the compass of curiosity.

Happy Exploring!

Chapter 2

Cell: The Building Block of Life



It is widely accepted amongst the scientific community that life originated in water. Some researchers believe that life may have originated in small water pools with changing environmental conditions rather than in the oceans. Hot springs are examples of such environments. In India, the hot springs of Puga Valley in Ladakh maintain very high temperatures (nearly at the boiling point of water) even in a cold climate. These environmental conditions seem to be similar to those on the early Earth, about 3.5 billion years ago. The organisms living in these hot springs are mostly heat-loving bacteria called **thermophiles**, which are unicellular.

Think It Over

- Where does a cell come from?
- How have technological interventions facilitated the creation of new knowledge in understanding the world beyond the naked eye?
- How is the cell structural and functional unit of life?
- How does a cell multiply?

Scientists from the Birbal Sahni Institute of Palaeosciences, Lucknow, studied these hot springs and found that calcium carbonate formed rapidly around them. These deposits may have protected early organic molecules from harmful radiation and extreme conditions, and they may have also helped in the formation of the first protective membrane — the barrier that defines a cell.

All living organisms are made up of cells. The cell represents the basic level at which life exists. Some organisms, such as bacteria or yeast consist of only one cell (unicellular), while others like plants, fish, birds or humans are made up of millions of cells (multicellular) that work together. A group of similar cells performing similar functions forms tissues. Different tissues are organised to form an organ and several organs work together to form organ systems. Such as, nasal pores, nasal cavity, trachea and lungs form respiratory system.

Even when cells are organised into tissues, organs, and organ systems the cell remains the fundamental unit of structure and function in all living organisms. This makes us wonder how such tiny cells perform so many different activities. What are the different components of a cell? How do cells in our body communicate with each other? Do cells live forever, or do they die? In this chapter, we will explore the answers to these questions as we enter the fascinating world of cells!

2.1 How to Study Cells?

What do we call the ability of the human eye to see two very close objects as separate and distinct? Imagine two tiny dots drawn on a piece of paper. As the dots are moved closer, there comes a point at which they can no longer be seen as separate. When viewed from about 25 cm (the near point of human eye), two points separated by about 0.1 mm can be seen as distinct; otherwise, they appear as a single point. This is called the **limit of resolution** of the human eye, which is 0.1 mm.

A cell is usually too small to be seen by the unaided eye (Fig. 2.1). This raises an important question—how have cell biologists studied the structure and function of cells that are much smaller than the limit of resolution of the human eye?

You have learnt about convex lens. A convex lens or a combination of lenses, i.e., an objective lens and an eyepiece are used for the **magnification** of an object (Fig. 2.1) to make it appear larger.

Grade 8 Curiosity Chapter 10

Robert Hooke was the first person to observe a cell in 1665 using a self-designed microscope (capable of about 200–300X magnification). While examining a thin slice of cork, he observed small box-like compartments and named them 'cells'. In school laboratories, light microscopes are used to observe objects using

Grade 8 Curiosity Chapter 2

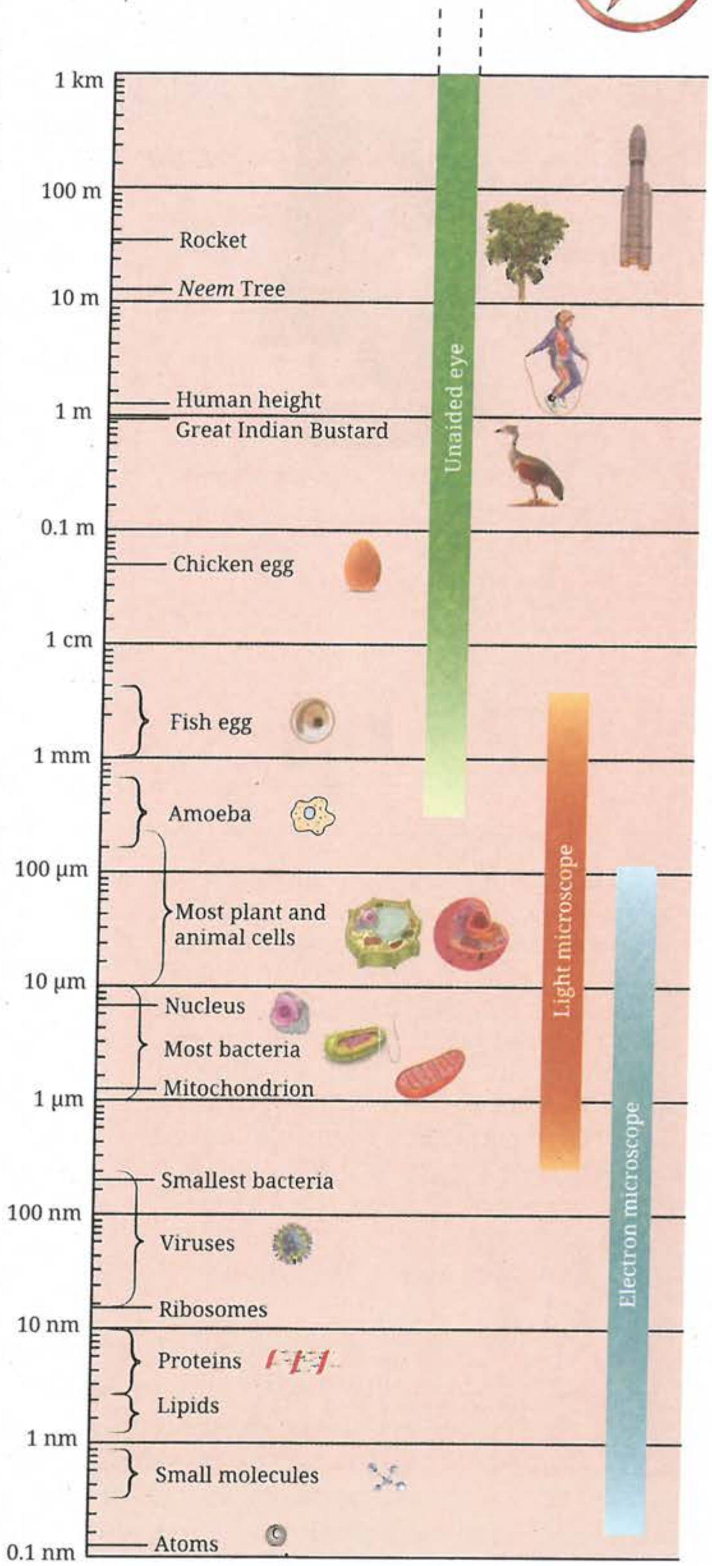


Fig. 2.1: Size of the objects and its visibility through unaided to aided eye

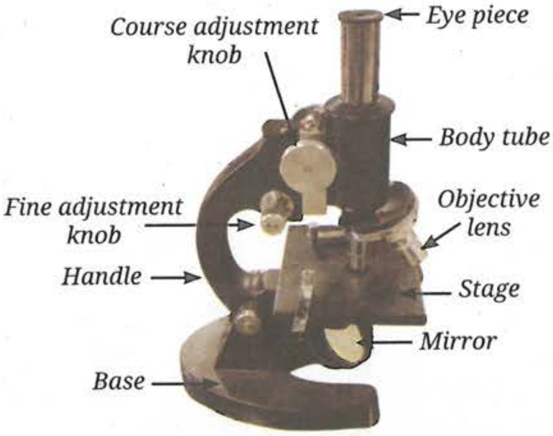


Fig. 2.2: Structure of a light microscope

different objective lenses (e.g., 10X, 40X) to achieve better magnification and resolution under visible light. Explore different parts of a microscope (Fig. 2.2) in your school laboratory and use it to observe fine structures of various materials. Under the microscope, you will see a magnified image of an object. Can you estimate its actual size?

Grade 8 Curiosity Chapter 9

Ready to Go Beyond


Fig. 2.3: An electron microscope

Apart from light microscopes, scientists also use powerful electron microscopes that reveal the fine details of a cell structure. These instruments use a beam of electrons instead of light to produce highly magnified images, allowing us to see cell structure at the nanometre scale with remarkable clarity (a nanometre is one-billionth of a metre).

Activity 2.1: Let us estimate the size of a cell

1. Take a transparent ruler with millimetre (mm) markings.
2. Place the ruler on the stage of microscope, focus on it using the adjustment knob and **observe** the diameter of the circular field of view through the eyepiece and measure it in mm.
3. Convert the diameter from mm to micrometre (µm). Suppose the diameter of the visible field is 5 mm, meaning 5 × 1000 = 5000 µm.
4. Remove the ruler and place an onion peel slide on the stage of the microscope.
5. Focus on the slide and count the number of cells present along the diameter of the field of view in one straight line.
6. **Estimate** the real size of the cell using the formula:

Unit conversion:
1 millimetre (mm) = 1000 micrometre (µm)

$$\text{Estimated size of the onion peel cell} = \frac{\text{Diameter of the visible field in micrometre}}{\text{Number of cells along the diameter}}$$

Suppose, 25 cells are seen along the diameter. In that case, the size of one onion cell would be 5000 µm/25 = 200 µm.

If the estimated size of an onion peel cell is 200 µm, how much does a light microscope magnify this cell? The total magnification of a microscope depends on its magnifying power of the eyepiece and the objective lens. If both the eyepiece and the objective lens have the magnifying power of 10X, then the total magnification will be 100X. This means that a cell with an estimated size of 200 µm will appear 100 times larger.

Thus, a microscope allows us to see very small structures clearly and is an essential tool for studying the cell structure. Over the years, scientists have improved the microscope by improving its three main features — resolution (measure of clarity), contrast (the difference in brightness between various parts of an object), and magnification. These improvements have turned microscope into a powerful tool for studying cells.

You can see a picture of the lower surface of *Colocasia* leaf observed under a Scanning Electron Microscope (Fig. 2.4).

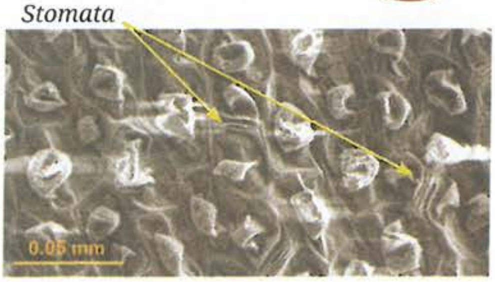


Fig. 2.4: Electron micrograph of lower surface of a Colocasia leaf showing stomata

2.2 Structure of a Cell

You have learnt that cells are organised into specialised tissues and organs, and collectively perform specific function. For these cells to function as units, they must be able to interact with one another and with their surroundings. These interactions occur at the cell boundary, where substances move between the cells and their external environment. Even single-celled organisms exchange materials and respond to their environment through cell membrane.

2.2.1 Cell membrane — The universal feature of a cell

The cell membrane is a thin boundary that surrounds a cell and protects its contents. It defines the individuality of a cell and is also called the **plasma membrane**. The cell membrane is selectively permeable, which means it allows some substances to pass through it while blocking others. You have learnt how oxygen and carbon dioxide move across the membranes of alveoli in the lungs. How does the structure of the cell membrane in the cells of alveoli control the movement of substances across it?

Grade 7 Curiosity Chapter 9

Activity 2.2: Let us experiment

1. With the help of a kitchen knife, carefully cut a potato into two pieces of roughly equal size (Fig. 2.5).
2. Measure and record the initial weight of both the pieces using a weighing balance.
3. Put one piece of the potato in Beaker A with plain water.
4. Put the other piece of the potato in Beaker B with 20 per cent salt or sugar solution.
5. Leave them undisturbed for about an hour or until you notice a visible change in the size of the pieces.
6. Measure and record the final weight of each piece.
7. Calculate the difference between the initial and their final weights.

What do you observe? You may observe that—

Beaker A— The potato piece swells.

Beaker B— The potato piece shrinks.

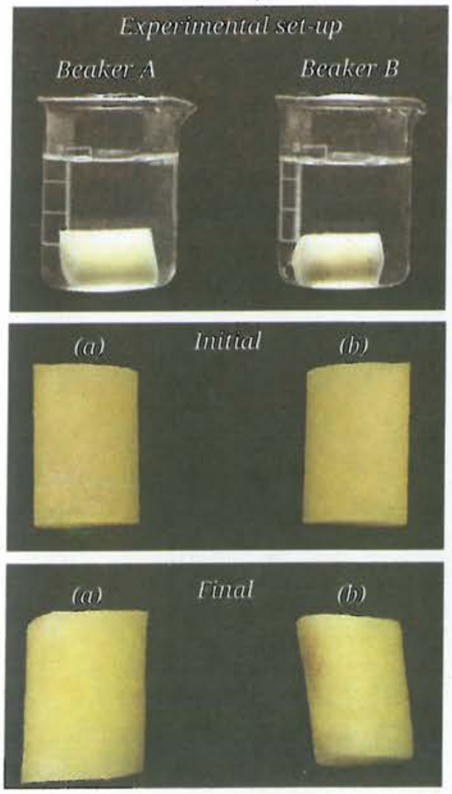


Fig. 2.5: Experimental set-up, and initial and final states of potato pieces in (a) plain water, and (b) 20 per cent salt solution

What if...

mung bean seeds are kept in a concentrated solution after soaking in water for 12 hours? What will happen to them?

What do you **infer**? What do you expect in terms of changes in their weight? The weight of the potato piece in Beaker A has increased, while the weight of the potato piece in Beaker B has decreased. This happens because the cell membrane allows water to move in and out of the cell but not the sugar or salt molecules. Water moves from an area with more water and less solute (dilute solution) to an area with less water and more solute (concentrated solution) until the concentrations in the two areas become equal. This movement of water through a selectively permeable membrane is called **osmosis**. You have learnt in Activities 7.8 (dye spreading in water) and 7.9 (fragrance spreading in air) in Grade 8 that particles of matter intermix, due to a difference in their concentrations, also called a concentration gradient. **Diffusion** is the net movement of particles from a higher to a lower concentration (which occurs even without a membrane). Osmosis is the diffusion of water across a selectively permeable membrane. In plants, water from the soil enters root cells by this process of osmosis.

Grade 8 Curiosity Chapter 7

What if...

a cell is kept in salt or sugar solutions of different concentrations?

Solute concentration of extracellular medium = Solute concentration of intracellular medium — Isotonic solution

Solute concentration of extracellular medium < Solute concentration of intracellular medium — Hypotonic solution

Solute concentration of extracellular medium > Solute concentration of intracellular medium — Hypertonic solution

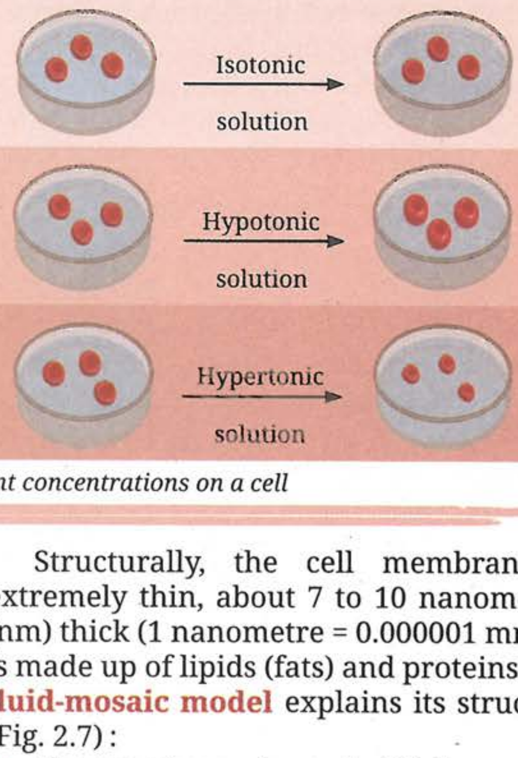


Fig. 2.6: Effect of solutions of different concentrations on a cell

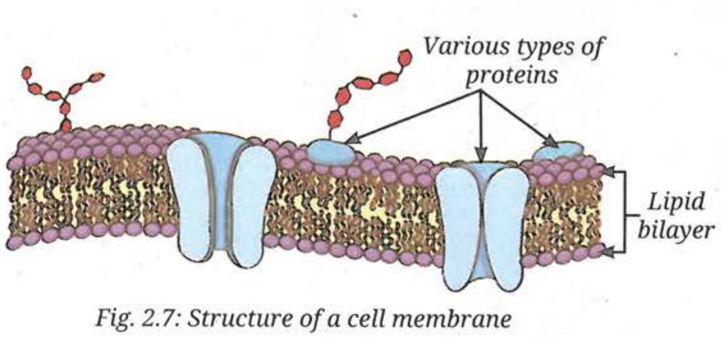


Fig. 2.7: Structure of a cell membrane

Structurally, the cell membrane is extremely thin, about 7 to 10 nanometres (nm) thick (1 nanometre = 0.000001 mm). It is made up of lipids (fats) and proteins. The **fluid-mosaic model** explains its structure (Fig. 2.7):

- The membrane has a lipid bilayer (two layers of special fat molecules with water attracting heads outwards and water repelling tails inwards) with proteins embedded in them.
- The molecules can move sideways, flip and rotate within the membrane. Hence, it is **fluid**.
- Proteins in the membrane act like gatekeepers in helping substances pass through.

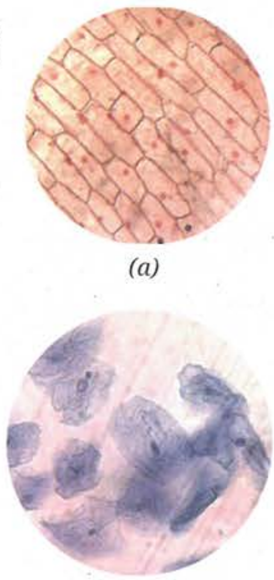
- Since the molecules are arranged like tiles in a mosaic, it is called the **'mosaic'** model.

All living cells communicate with their surroundings and their neighbouring cells through the cell membrane. However, cells of plant, fungi, and bacteria have an additional layer around the cell membrane, called the cell wall. What do you think is the necessity of the cell wall in these cells?

Activity 2.3: Let us investigate

1. Prepare temporary slides of a thin peel of an onion leaf or a *Rhoeo* (Cradle lily) leaf and mount it with safranin using cover slip to observe plant cells under a microscope.
2. Similarly, prepare a temporary slide of cheek cells by gently scraping the inner side of your cheek with a cotton swab or the blunt end of a toothpick.
3. Spread the cheek cells on a clean glass slide.
4. Add a drop of water followed by a few drops of methylene blue stain and carefully place a coverslip.
5. Observe both the slides under a microscope.

What do you observe? Onion peel cells (Fig. 2.8a) or *Rhoeo* leaf peel cells are box-shaped and regularly arranged, whereas cheek cells are irregularly arranged (Fig. 2.8b). Why do you think this difference exists?



(a)

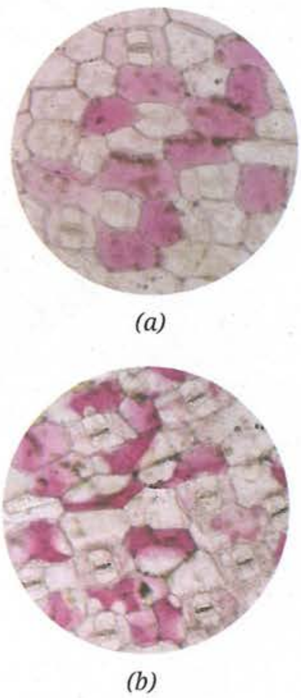
(b)

Fig. 2.8: (a) The onion peel cells, and (b) human cheek cells

Prepare two slides of a *Rhoeo* leaf peel and human cheek cells again, and put 20 per cent sugar solution on them. Observe them under a microscope after half an hour. What do you observe? You must have observed that the boundaries of the plant cells remain the same but their inner content shrinks, and the space between the inner and outer boundaries increases (Fig. 2.9a and b). You may observe that the cheek cells, on the other hand, have shrunk considerably.

2.2.2 Cell wall—The outer covering of cells

In general, plants cannot move from place to place, so they need a rigid structure to withstand environmental stresses like wind and rain. Therefore, plant cells have an additional covering outside the cell membrane called a **cell wall**. The cell wall also helps leaves and flowers remain firm, and maintain their shapes and help plants stay upright. Although rigid the cell wall is permeable, which means water and some dissolved minerals can pass through it. Along with the selective permeability of the cell membrane, the permeability of the cell wall helps plant roots absorb water and nutrients from the soil.



(a)

(b)

Fig. 2.9: Cradle lily leaf peel cells (a) in water, and (b) in 20 per cent sugar solution

When we place a *Rhoeo* leaf or an onion peel in a concentrated sugar solution the plant cells lose water due to osmosis. However, the cells do not shrink in size because their rigid cell wall maintains their shape. The inner content of a cell shrinks as the cell membrane pulls away from the cell wall. This shows that the cell wall helps plant cells remain firm in their original shape.

Animal cells, such as cheek cells do not have a cell wall. Therefore, when placed in a concentrated sugar solution, they lose water and shrink.

Without a rigid cell wall, animal cells can change shape easily. This cellular flexibility supports the overall movement and functioning of animal tissues.

The plant cell wall is primarily made of cellulose, a type of carbohydrate formed by many glucose units linked together. Cellulose in our diet acts as roughage, helping in digestion. Some microorganisms, like fungi and bacteria also have a cell wall to provide protection and structural support to their cells.

Pause and Ponder

1. What argument would you give for the necessity of a cell wall in plants usually fixed in one place versus in animals usually moving from one place to the other?
2. What consequences would you predict for a plant cell if its cell wall were to become as flexible as a cell membrane?
3. Why is it important to cut the two potato pieces in roughly equal size and measure their initial weight before placing them in different liquids?

2.3 The Cell Interior — A Coordinated Working System

You have learnt that most cells have three basic parts:

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- a selectively permeable membrane called the plasma membrane,
- a semi-fluid, jelly-like substance called the cytoplasm, and
- a prominent nucleus.

In addition to the nucleus, the cytoplasm contains several sub-cellular components called **organelles,** along with other substances present in it, most of which are only visible with an electron microscope.

Activity 2.4: Let us study

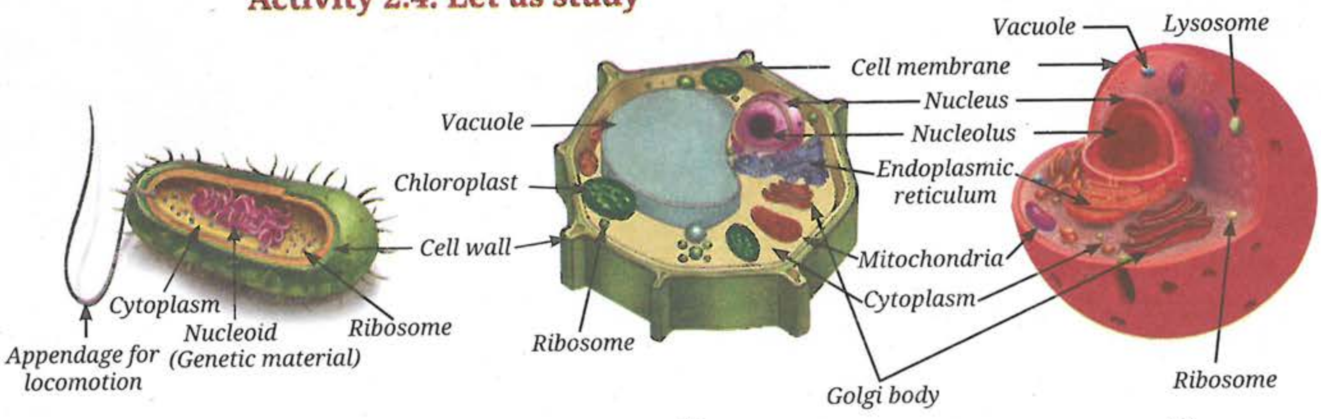

Fig. 2.10: (a) A typical bacterial cell, (b) a typical plant cell, and (c) a typical animal cell

1. Study the given diagrams of a bacterial cell, a plant cell, and an animal cell (Fig. 2.10a, b and c).
2. Observe the different structures present in each of them.
3. Record your observations in Table 2.1.

A bacterial cell lacks a well-defined nucleus and membrane-bound organelles (organelles surrounded by their own membranes). Such cells are called **prokaryotic cells** (*pro* means primitive and *karyon* means nucleus). In prokaryotic cells, most cellular activities take place directly in the cytoplasm. In contrast, plant and animal cells have a well-defined nucleus and several membrane-bound organelles. Such cells are called **eukaryotic cells** (*eu* means true, and *karyon* means nucleus). More details of the characterstics of prokaryotic and eukaryotic cells is given in Table 2.2.

Table 2.1: Comparison of different kinds of cells based on their structure

S. No.	Cell structures	Bacterial cell	Plant cell	Animal cell
1.	Cell membrane			
2.	Cell wall			
3.	Cytoplasm			
4.	Well-defined nucleus (genetic material enclosed by a membrane)			
5.	Primitive nucleus (nucleoid) (genetic material without membrane around it)			
6.	Membrane-bound organelles			

Table 2.2: Comparison between prokaryotic and eukaryotic cells

Characteristics	Prokaryotic cell	Eukaryotic cell
Primitive nucleus	Present	Absent
Diameter of a typical cell	1 to 10 µm	10 to 100 µm
Number of cells in an organism	Usually unicellular	Can be unicellular or multicellular
Membrane-bound organelles	Absent	Present
Membrane-bound nucleus	Absent	Present

Which of the cells given in Fig. 2.10 fall under the categories of prokayotic and eukaryotic cells?

Ready to Go Beyond

Viruses, viroids, and prions are acellular (no cells) infectious agents that are too small to be seen under a light microscope. Viruses are composed of some genetic material with a protein coat. Viroids lack protein coat around its genetic material, while prions are misfolded proteins which lack genetic material.

Ready to Go Beyond

In eukaryotic cells, a network of fine fibres forms the cytoskeleton, which provides structural support, maintains cell shape, and enables cell movement and internal transport. It is visible only under an electron microscope as a separate entity. The cytoplasm may also store starch (in plant cells), or crystals of calcium oxalate or silica (in some plant cells). These are known as cell inclusions.

2.3.1 Why do eukaryotic cells need these organelles?

Eukaryotic cells carry out various life processes in different cell organelles independently at the same time.

Cell organelles help in building new materials, removing waste, and providing energy to the cell. They work together to perform all functions of a cell. In other words, a cell is like a tiny living factory, with each of its part doing a specific job.

Let us explore these specialised structures present inside a cell.

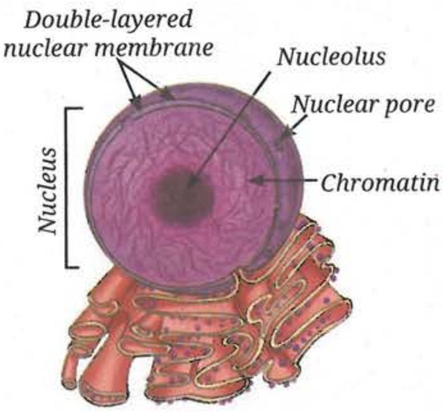

Fig. 2.11: Structure of a nucleus

Nucleus — House of coded instructions

The nucleus has a double-layered covering called the nuclear membrane, which has pores that allow the transfer of material between the nucleus and the cytoplasm. The nucleolus is the dense round body in the nucleus, where synthesis of ribosomal subunits take place. These subunits then exit the nucleus to cytoplasm where one large and one small subunits assemble to form ribosome (Fig. 2.11).

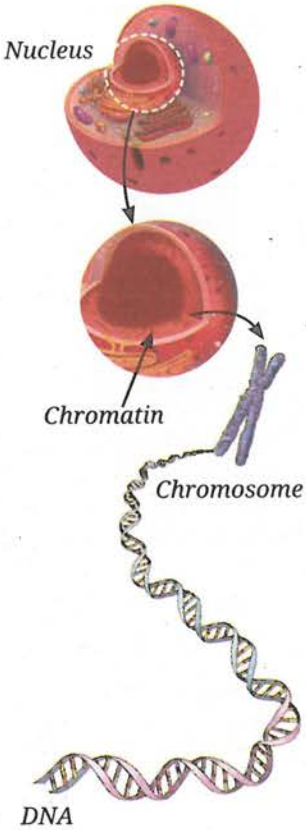

Fig. 2.12: From cell to DNA

The nucleus contains chromosomes, which are visible as rod-shaped structures only when the cell is about to divide. Chromosomes contain information for inheritance of characters from parents to the next generation in the form of DNA (Deoxyribonucleic acid) molecules. Chromosomes are composed of DNA and specific proteins. DNA molecules contain the genetic information. The functional segments of DNA are called genes. In a non-dividing cell, this DNA is present as part of chromatin material. Chromatin material is visible as an entangled mass of thread-like structures. Whenever the cell is about to divide, the chromatin material gets organised into chromosomes (Fig. 2.12).

Threads of Curiosity

Some cells are specialised to perform specific functions. For example, mature Red Blood Cells (RBCs) in humans do not have a nucleus (enucleate). The absence of a nucleus provides more space for haemoglobin, allowing it to transport a larger amount of oxygen to all cells of the body. Since they lack a nucleus, they cannot repair or divide themselves. As a result, their lifespan is short and they survive approximately for 120 days. Do you know any other cells without nucleus?

Prokaryotic cells do not have a well-defined nucleus. Their DNA is present as a single circular molecule associated with specific proteins. The region containing this genetic material is called the **nucleoid**.

Ribosomes — The protein factories

These are tiny structures may be present either freely in the cytoplasm or attached to the endoplasmic reticulum. Ribosomes are the sites of protein synthesis.

Endoplasmic Reticulum (ER) — Manufacturing factory

The Endoplasmic Reticulum (ER) is a large organelle that spreads like a network within the cytoplasm of the cell. The ER is continuous with the outer membrane of nuclear envelop. The ER plays a key role in the synthesis and transport of proteins, fats (lipids), and some hormones in some of the specialised cell. The structure of the ER in a cell varies depending on its function. There are two types of ER:

- **Rough Endoplasmic Reticulum (RER):** It looks rough under an electron microscope because it has ribosomes attached to its surface, and is mainly involved in protein synthesis and protein secretion (for example, in gland cells, such as pancreatic cells).
- **Smooth Endoplasmic Reticulum (SER):** It does not have ribosomes on its surface, and therefore, looks smooth. It is involved in the synthesis, and storage of fats and hormones (Fig. 2.13).

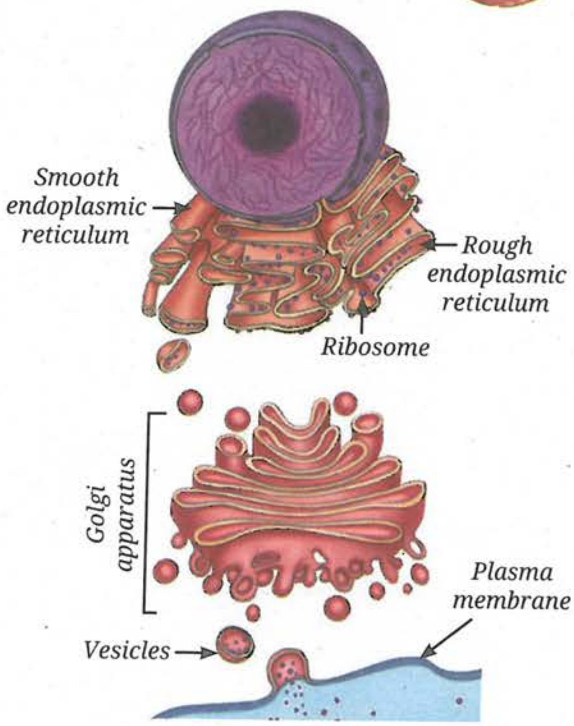

Fig. 2.13: Endoplasmic reticulum and Golgi apparatus — pathway for protein processing and secretion

Golgi apparatus — The packaging and shipping centres

If you carefully look at the diagram of a cell (Fig. 2.10b and c), you will notice stacks of flattened, sac-like structures. Together, these stacks form the Golgi apparatus (Fig. 2.13). It is functionally linked to the ER, the cell membrane and the other cell organelles. The Golgi apparatus acts like the cell's post office. It modifies, sorts, and packages proteins and/or lipids into vesicles for transport, secretion, or lysosome formation.

Meet a Scientist

The **Golgi apparatus** was first observed in 1898 by an Italian scientist, **Camillo Golgi**, in the nerve cells of a barn owl. Using special staining techniques, he observed a thread-like network. Early microscopes could not resolve it clearly, therefore, many doubted its existence. However, electron microscope observations confirmed it decades later.

When the structure was clearly seen and confirmed, it was named the 'Golgi apparatus' in his honour.

Lysosomes — The clean-up system

Cells produce waste materials and damaged, worn-out organelles during their activities. How does the cell prevent these wastes from accumulating inside it?

Lysosomes are single membrane-bound sacs filled with enzymes, which can break down unwanted proteins, carbohydrates, fats, and even damaged parts of the cell, keeping it clean and healthy. The products formed by the breakdown are released into the cytoplasm, where they may be reused in other cellular processes.

Threads of Curiosity

Human sperm cells contain lysosomal enzymes. When a sperm meets an egg, these enzymes help break down the outer layer of the egg, allowing fertilisation to take place. You will learn about the human sperm cells later in Chapter 11.

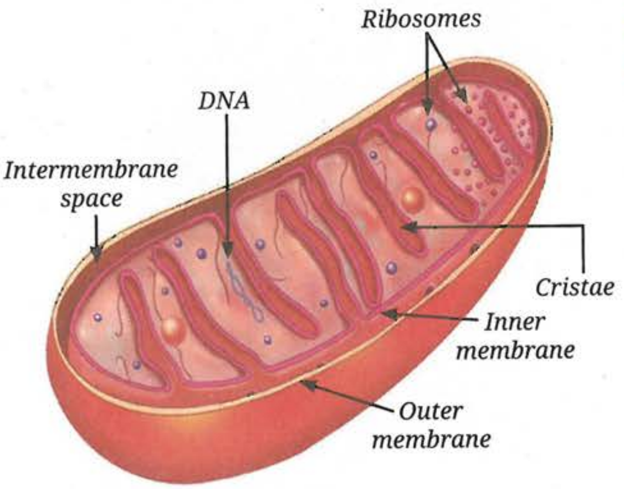

Fig. 2.14: Structure of a mitochondrion

Mitochondria — The powerhouse of the cell

Mitochondria are often called the 'powerhouses of the cell' because they supply the energy needed for most cellular activities. Each mitochondrion (Fig. 2.14) is surrounded by two membranes :

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- The **outer membrane** is smooth and porous.
- The **inner membrane** is folded into finger-like projections called **cristae**, which increase the surface area for chemical reactions and facilitate energy production.

In mitochondria, the glucose and other molecules are broken down to release energy during a process called cellular respiration. You have already studied about it. The energy released is stored in the form of a molecule called Adenosine Triphosphate (ATP), which acts as the energy currency and is used for most of the cellular activities.

Plastids — Centre for food synthesis in the plant cells and beyond

You have learnt that mitochondria provide energy to the cell that comes from food. Animals can obtain food from their surroundings, however, plants synthesise food in the presence of sunlight. But where do plants synthesise their food and obtain energy for cellular activities? Plants use special organelles called **plastids** for food synthesis and storage.

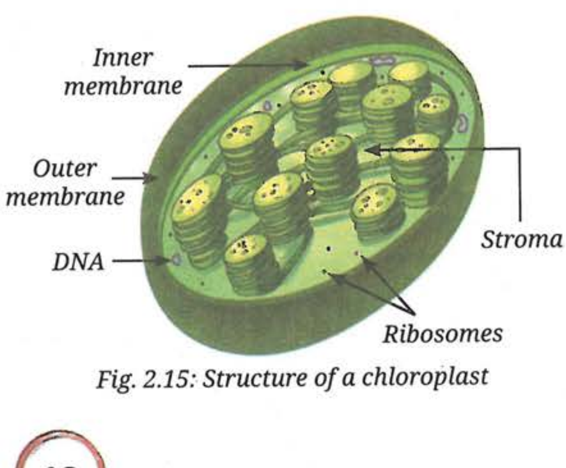

Fig. 2.15: Structure of a chloroplast

As you have learnt, plants prepare their food by the process of photosynthesis in the presence of sunlight. A green pigment called **chlorophyll**, which is present in the chloroplast (a type of plastid) absorbs sunlight. Chloroplasts are double-membrane-bound organelles, like mitochondria. Inside the chloroplast (Fig. 2.15) there is a semi-fluid substance called the **stroma**. Within the stroma are disc-shaped membrane structures that contain chlorophyll. Light energy is absorbed

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by them during photosynthesis. The sugars synthesised in this process are stored in stroma, along with the starch granules.

Mitochondria and plastids have some features that are similar to certain bacteria. For example, they both have their own DNA and ribosomes, and thus, they can make some of their own proteins. These characteristics suggest that both mitochondria and plastids share an evolutionary history with these single-celled organisms.

Are there any other plastids in plant cells that contain any pigments other than the green pigments?

How do flowers, fruits, and vegetables acquire varied colours?

In flower petals and fruits, plastids contain pigments other than chlorophyll. These plastids are called chromoplasts (in Greek, *chroma* means colour). Their pigments (may be yellow, orange or red) are the source of bright colours in such flowers and fruits. Such bright colours help in attracting pollinators for pollination and fruit-eating animals that help in seed dispersal.

Some plastids lack pigments and are thus, colourless. These are called **leucoplasts** (in Greek, *leukos* means white). Leucoplasts store food material, such as starch, oils or proteins and are classified based on the type of food they store. For example, some leucoplasts in potato and taro *(Colocasia)* cells store starch.

Vacuoles — The organelles for storage and support

Plastids, such as chloroplasts help plants produce food and temporarily store it. Other plastids, such as leucoplasts help in storing food. But where are water, minerals, and waste materials stored in the cell? Why do plants look wilted when they do not get enough water?

In a mature plant cell, there is usually one **large central vacuole** surrounded by a single selectively permeable membrane. The vacuole is filled with a watery fluid called **cell sap**. The vacuole stores water, minerals, sugars and waste material. By storing large amounts of water, the vacuole helps maintain pressure inside the cell, which keeps a plant cell firm. When a plant does not get enough water, the vacuole loses water, the cells become less firm, and the plant gets wilted.

In animal cells, vacuoles are sometimes present. Although they are not as large as plant vacuoles, they help in the temporary storage of materials.

Pause and Ponder

4. Do white flowers contain any pigment? Give reasons.
5. Draw a well-labelled schematic diagram of a plant or an animal cell using these clues —
   (i) Nucleus appears as a dark and round body inside the cell.
   (ii) ER spreads like a network of extended nuclear envelope.
   (iii) Mitochondria and chloroplasts are rod shaped.

You may refer to Fig. 2.10.

Threads of Curiosity

In 2010, scientist J. Craig Venter and his team made an important discovery in the field of synthetic biology. They first studied the complete DNA sequence of a simple bacterium called *Mycoplasma mycoides* using a computer programming. Then, they chemically synthesised (in the laboratory) an exact copy of this DNA.

Next, they took another closely related bacterium and removed its DNA, but kept the rest of the cell (such as the cytoplasm and the cell membrane) intact. They inserted the synthetic DNA into this cell. After this, the cell started to grow and divide, following the instructions from the newly inserted synthetic DNA. This experiment showed that DNA controls the structure and activities of a cell.

However, scientists did not create a completely new cell from scratch. Only the DNA was synthetic. The other parts of the cell were taken from an already existing living cell.

Fig. 2.16: Growing roots of an onion in a jar containing water

2.4 How do Normal Cells Grow and Divide?

When you get a small cut on your skin, it heals after a few days. When hair fall out, new hair grow back. How does this happen? It happens because **cells in our body can grow and divide** to replace the old, dead, or damaged cells. When our body grows, it is not just because cells get bigger. Cells can grow only up to a certain size but growth happens because cells divide to form new cells. Let us study freshly growing root tips of an onion to understand how cells divide (Fig. 2.16).

Activity 2.5: Let us enhance our skills

1. Take a jar and fill it up with plain water.
2. Now, place an onion bulb over the jar in such a way that its base bearing roots, is immersed in the water.
3. Leave the setup for 5–6 days and observe. Do you observe the roots growing? Cut 2–3 cm of the freshly grown roots and transfer them to freshly prepared aceto-alcohol (glacial acetic acid:ethanol :: 1:3). Keep the root tips in aceto-alcohol for 24 hours and then transfer them to 70 per cent ethanol (for preservation).
4. Take one or two preserved roots, wash them in water and then, place them on a clean slide.
5. Put one drop of dilute Hydrochloric acid (HCl) on the root tips to soften the tissue. Rinse the roots after 10–15 minutes. Then add 2–3 drops of aceto-carmine stain on them.
6. Leave the slide for 5–10 minutes and then, gently warm it (with caution) over a spirit lamp.
7. Cut the tip portion of the root on the slide and put a coverslip. Gently squash the coverslip with your thumb to spread the cells on the slide.
8. Observe the slide under a microscope.

What do you observe? Do you observe the cells of the onion root tip? Are they similar in structure? Do you find any structural differences in these cells? If yes, why is it so?

This is because the cells of a growing tip of root of onion divide continuously. This process is called **cell division**. Fig. 2.17 shows various stages of cell division. Therefore, these cells exhibit different structures corresponding to different stages of cell division. Can you identify which stage comes first during cell division?

Every day, an estimated hundreds of billions of cells in our body are replaced, which is almost 1 per cent of the total number of cells in our body. Both prokaryotic and eukaryotic cells divide, but eukaryotic cells divide in a more controlled and orderly manner by a process called the **cell cycle**. Next Level Up You will learn about the stages of cell division in higher grades.

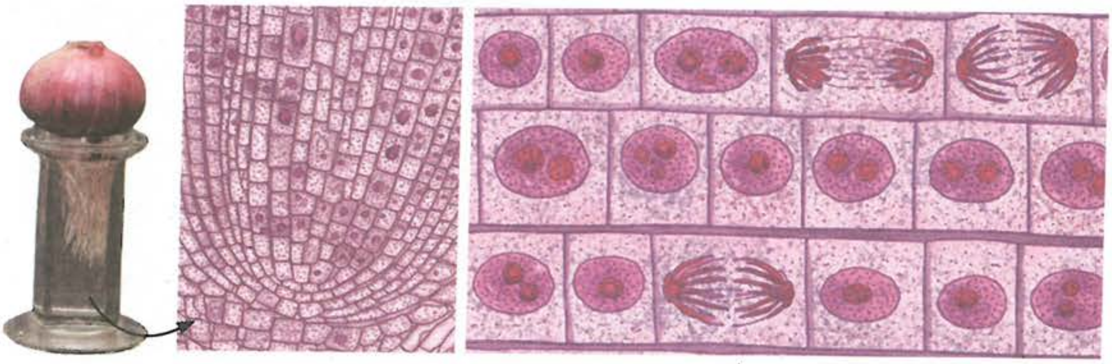

Fig. 2.17: Different stages of cell division in onion root tip cells

2.4.1 Cell division

Cell division is the process by which new cells are formed from pre-existing cells. It allows living organisms to grow, repair damaged tissues and reproduce. Some cells, such as skin cells divide continuously to replace cells that are lost regularly. There are two major types of cell division — **mitosis and meiosis**. Mitosis is important for normal growth, repair, maintenance and asexual reproduction, while meiosis is important for sexual reproduction for creation of genetic diversity.

Mitosis

Every human begins life as a single fertilised egg. This one cell divides repeatedly to form trillions of cells in the body. Cells increase in number through mitosis, which is the most common type of cell division (Fig. 2.18).

Mitosis produces two genetically identical daughter cells from one parent cell. Each new cell gets the same DNA and the same number of chromosomes as the parent cell. This ensures that genetic information is largely maintained across body cells.

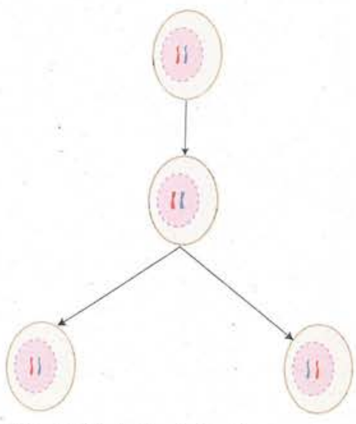

Fig. 2.18: Mitosis is the process that produces two genetically identical daughter cells

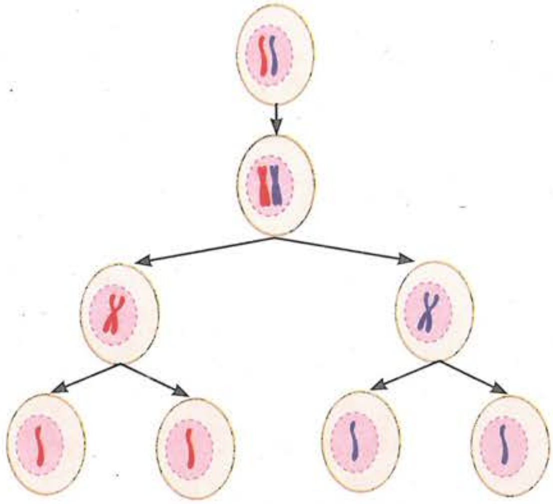

Fig. 2.19: Meiosis is a two-step process that produces four gametes

Meiosis

Meiosis is a type of cell division that produces gametes and occurs only in the cells of reproductive organs. Gametes produced for sexual reproduction create variations and diversity among living organisms. Therefore, children resemble their parents but are not exactly the same. In animals including humans, meiosis occurs only in the cells of **testes** of males to produce sperm and **ovaries** of females to produce eggs. In plants, meiosis occurs in the **anthers** (male parts) to form pollen grains (that later produce sperm cells) and the **ovaries** (female parts) to produces egg cells. In meiosis, the parent cell divides twice, one after the other, to form four daughter cells (Fig. 2.19). During the first division, the cells divide into two daughter cells and the number of chromosomes in each daughter cell is reduced to half. The second division is similar to mitosis where each daughter cell divides into two thus, forming four daughter cells with half the number of chromosomes. As a result, each gamete has half the number of DNA compared to the parent cell. During fertilisation, when gametes from two individuals combine, the original chromosome number is restored. You will learn about this process in detail in Chapter 11.

Next Level Up

Meet a Scientist

Arun Kumar Sharma was a famous Indian scientist known for his work on chromosomes. As a botanist, he is known for his work in the area of plant taxonomy, evolution and development. He also invented many useful lab methods to study chromosomes in plants. For his contributions to botany, he received many honours, including the Shanti Swarup Bhatnagar award and Padma Bhushan.

Bridging Science and Society

Scientists have developed methods to grow plant and animal cells outside the body in special conditions. This is called cell culture. In this process, cells are taken from an organism and placed in a nutrient-rich medium that allows them to grow and multiply. To keep the culture safe, the right temperature, acidic or alkaline conditions and moisture under sterile conditions are maintained. Cell culture is crucial for studying how cells work and for the production of biochemicals, food, medicines, vaccines, and more.

Pause and Ponder

6. Instead of many small ones, why does a cell not have a single giant mitochondrion? How does this relate to the concept of surface area?
7. If the skin cells start dividing by meiosis instead of mitosis, what do you think will happen to a cut on the skin?

The processes of mitosis and meiosis must occur in a proper and controlled manner. What happens if meiosis and mitosis do not happen properly? If there is any error in these processes, it can lead to various problems in the body of an organism.

Errors in mitosis lead to uncontrolled cell divisions. This can lead to the formation of tumours and abnormal number of chromosomes in body cells.

Errors in meiosis may result in genetic disorders, which may be associated with developmental problems or distinctive physical features. Faulty meiosis may also cause early pregnancy loss or reduced fertility.

2.5 Cell Theory — The Unifying Principle of Biology

An important observation about living organisms is that all organisms are made up of cells. In 1838, a German botanist named Matthias Schleiden reported that all plants are made up of cells. In 1839, German zoologist Theodor Schwann, found that all animals are also made up of cells. Later, in 1855, a German scientist named Rudolf Virchow, further expanded the **Cell Theory** by stating that new cells are formed only from pre-existing cells. Together, their work led to the formulation of the Cell Theory.

According to the classical Cell Theory:

- All living organisms are made up of one or more cells.
- The cell is the basic unit of structure and function in living beings.
- All cells arise from pre-existing cells.

This unifies all biology, from bacteria to humans, and explains life's continuity through cell division.

2.5.1 Do cells grow and reproduce forever?

Cells grow and divide in a controlled way, stay in the right place, carry out their functions, and eventually die when they are no longer needed. Dead cells are replaced by new cells that carry out the same function. Thus, every cell has a definite life span. If cells do not die when they should or if they die too early problems can arise in the body. In many animal cells, cell division usually stops when cells come in contact with neighbouring cells. This process is called **contact inhibition**. However, cancer cells lose this control and keep dividing uncontrollably, leading to the formation of **tumours**. Plant cells grow differently. Due to their rigid cell walls plant cells do not show contact inhibition and follow a different pattern of growth.

Even though cells are extremely tiny they perform remarkable functions. They produce energy, synthesise and secrete substances, divide to form new cells, and work together to maintain the proper functioning of the body. Every living being from a tiny bacterium to a giant tree is made up of cells. You are one of the products of these tiny hardworking cells.

Ready to Go Beyond

How do cells monitor their growth to maintain a balance?

Cells also have natural ways of dying to maintain a balance. Programmed Cell Death (PCD) is a genetically regulated and organised process of selective cell destruction. It is essential for normal development, cellular quality control and immune function. When an embryo develops, the PCD helps form fingers by eliminating cells between digits, without it we would have webbed hands.

Explore different ways by which cells maintain themselves.

Meet a Scientist

In 1902, the Austrian botanist, **Gottlieb Haberlandt**, proposed that **any living plant cell**, even a fully mature cell from a permanent tissue, can develop into a complete plant if it is provided with suitable nutrients and favourable conditions. He suggested that plant cells have the ability to form different types of cells and also change them. This special ability of plant cells is called totipotency. Haberlandt's idea laid the foundation for a new branch of biology known as **Plant Tissue Culture Technology.**

Threads of Curiosity

How do cancer cells grow and spread?

Normal cells grow, age and die in a controlled manner. Sometimes, this system breaks down, and abnormal cells start growing and dividing uncontrollably. This results in the formation of tumours, which may be benign or malignant. Cancerous tumours can invade nearby tissues and even spread to other parts of the body to form new tumours.

At a Glance

- The cell is the basic structural and functional unit of all living organisms.
- Prokaryotic cells do not have a well-defined nucleus, instead their genetic material is present in a region called the nucleoid. They also lack membrane-bound organelles.
- Eukaryotic cells are larger and more complex. They have a well-defined nucleus and several membrane-bound organelles.
- All cells are surrounded by a cell membrane. In addition, cells of plants, fungi and bacteria have a cell wall outside the cell membrane.
- The nucleus of eukaryotic cells contains chromosomes, which are composed of DNA and associated proteins, which carry genetic information.
- All cells are filled with cytoplasm. In eukaryotic cells, cytoplasm contains several cell organelles, each performing a specific function.
- Important cell organelles include the nucleus, endoplasmic reticulum, mitochondria, golgi apparatus, ribosomes and lysosomes.
- Plant cells also contain special organelles called plastids, such as chloroplasts, leucoplasts and chromoplasts.
- Mitosis produces two daughter cells identical to the parent cell.
- Meiosis is a two-step division process which produces four daughter cells, each having half the number of chromosomes.
- Normal cells grow in a controlled manner, perform their functions and die naturally, while cancer cells lose control and keep dividing uncontrollably leading to the formation of tumours.

Revise, Reflect, Refine

1. 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)
2. Two similar animal cells are placed in two different solutions:
   - Cell X is placed in pure water.
   - Cell Y is placed in a concentrated salt solution.

Cells are observed after some time. Cell X swells, and Cell Y shrinks. Which statement provides the correct explanation for the above observations?

(i) Salt molecules moved into Cell Y, causing it to shrink.
(ii) Water moved into Cell X and more water moved out of Cell Y than the salt solution entered in it.
(iii) Water moved into Cell X and moved out of Cell Y through the cell membrane.
(iv) Solute movement caused osmosis in both cells.

3. Look at the diagram of a cell in Fig. 2.20. Identify the parts labelled from (a) to (g) and correctly match them with their functions given below:
   (i) Controlling all the activities of a cell.
   (ii) Site of cellular respiration.
   (iii) Storage organelle that also provides rigidity to the cell.
   (iv) Separates the cell contents from surroundings.
   (v) Provides structural rigidity to the cell.
   (vi) Packs and stores materials received from ER.
   (vii) Helps in manufacturing food.

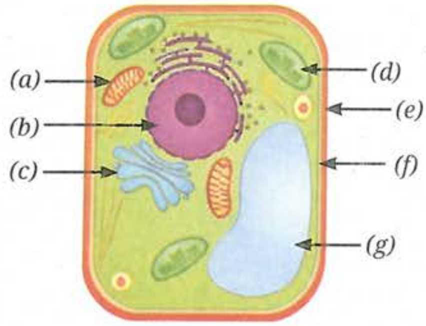

Fig. 2.20

4. Which of the following option(s) of the pairs of cell organelles are correctly placed under the given categories?

Option	Present in the plant cells	Absent in the animal cells
(i)	Leucoplast	Cell wall
(ii)	Mitochondria	Ribosome
(iii)	Cell wall	Golgi apparatus
(iv)	Lysosome	Endoplasmic reticulum

5. Two students, Renu and Rohit, were having a discussion on the plastids. Renu emphasised that all parts of the plants, even roots, contain plastids. However, Rohit did not agree with the statement and told her that plastids are absent in plant roots since the roots are underground and do not need to perform photosynthesis. Who is correct? Justify your answer.
6. Mitochondria and chloroplasts are two important organelles in a plant cell. Discuss how these two organelles are structurally and functionally similar to each other, and different from each other.
7. Which of the following pairs of cell organelles contains DNA?
   (i) Chloroplasts, Ribosomes
   (ii) Mitochondria, Nucleus
   (iii) Golgi bodies, Ribosomes
   (iv) Nucleus, Lysosomes

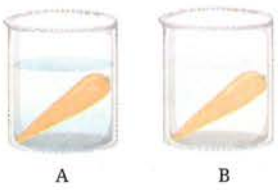

Fig. 2.21: Experimental set-up having carrot (a) in plain water, and (b) in salt solution

8. A researcher carried out an experiment in which she took two carrots of similar size. She placed one carrot in plain water and the other carrot in concentrated salt solution (Fig. 2.21). After 24 hours she recorded her observations.
   (i) What hypothesis does she want to test through this experiment?
   (ii) What would you suggest for the improvement of this experiment?
   (iii) Why does the carrot in plain water stay stiff and crunchy, but the carrot in concentrated salt solution become rubbery and limp?

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

Structures in a cell	Bacterial cell	Animal cell
Chromosome		
Nucleus		
Mitochondria		
Golgi complex		
Chromoplasts		

10. Carry out the following experiment:
    Take four peeled potato halves and scoop each one out to make potato cups. One of these potato cups should be made from a boiled potato. Place each of the potato cups in a beaker containing water (Fig. 2.22). Now, set up the experiment as follows:
    (a) Keep Cup A empty.
    (b) Add one teaspoon sugar in Cup B.
    (c) Add one teaspoon salt in Cup C.
    (d) Add one teaspoon sugar in the boiled potato in Cup D.
    Observe the four potato cups at least two hours and answer the following questions:
    (i) Explain why water gathers in the hollowed portion of Cup B and Cup C.
    (ii) Why is Cup A necessary for this experiment?
    (iii) Explain why water does not gather in the hollowed portions of Cups A and D.

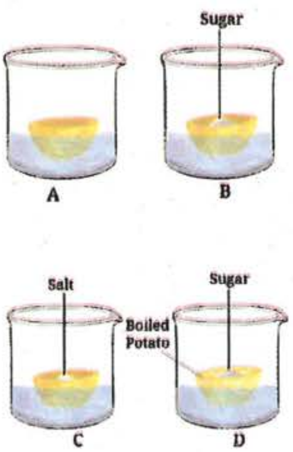

Fig. 2.22: Experimental set-up

11. Identify the pair that incorrectly matches the cell organelle with its function.
    (i) Ribosome — Protein synthesis
    (ii) SER — Lipid and cellulose synthesis
    (iii) Lysosome — Digestion of foreign agents

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

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

14. The cell membrane of a cell is made up of proteins and lipids. Which cell organelles help in the synthesis of cell membrane? Write the path of these compounds from their site of synthesis to the cell membrane and show this through a labelled diagram.
15. What would happen if gametes are formed by mitotic divisions?
16. A farmer, Deepa, was very happy with the harvest of *amla* (Indian Gooseberry) and lemons on her farm. However, she could sell only one-fourth of the produce in the local market. Recognising that a significant amount of produce may be lost post-harvest, she employed a traditional yet scientifically sound method to extend the shelf life of *amla* and lemons. She turned perishable produce into profitable products, such as pickles and *sharbat*. She used the excess produce to prepare pickles, *murabbas*, and *sharbat* by adding appropriate amounts of salt, sugar, or jaggery to small pieces of fruit and their juices. These were then stored in small glass bottles for sale, helping her prevent the wastage of post-harvest produce. This shift from farming to agro-processing would strengthen food security and boost the local economy, creating a sustainable model that cuts waste while increasing her income. Based on the above passage answer the following questions:
    (i) Which scientific concept has the farmer applied in the preservation of the farm produce?
    (ii) How does the addition of high concentrations of salt and sugar create an environment that prevents the growth of spoilage-causing bacteria and fungi?
    (iii) Suggest a healthy recipe of this kind for food preservation.
    (iv) What are the scientific values addressed in this case?

The Journey Beyond

- Use selected software or digital tools to create animations or simulations of cell division and share them in the class.
- Create a model of any type of a 'synthetic cell' using low-cost eco-friendly material.
- Build a mitosis or meiosis model with your classmates for your science project or exhibition. How did teamwork contribute to the success of the activity? Did this activity change your perspective or understanding of the cell division topic in any way? If so, explain how?
- Develop a *nukkad natak* for community awareness in simple dialogues about the different functions of cell organelles.

The Quest Continues ...

What is the future of the development of synthetic cells using non-living chemicals? If a synthetic cell is developed, what may be the related ethical issues?

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Chapter 3

Tissues in Action

Life begins when a single cell divides itself several times to give rise to a large number of cells. These cells gradually form the skin (protection), muscles (movement), bones (support), nerves (control and coordination), and all other organs. This process is so intricate that it is considered one of nature's greatest engineering marvels. Researchers have been trying to understand, replicate and modify this process for human welfare. To do so, it is essential to understand the natural biological processes that govern growth and development in plants and animals. What makes cells group together to form tissues? Why do some tissues grow throughout life while others do not?

Think It Over

- How is the study of cells and tissues significant for understanding the life processes and human welfare?
- How are tissues in plants and animals different, and why?
- How is the division of labour at various levels of organisation in multicellular organisms correlated with their structure and function?

In Chapter 2, Cell: The Building Block of Life, you have learnt that the cell is the basic unit of life. Many cells come together to form a multicellular organism. In all multicellular organisms, there is a hierarchy of organisation. Cells of similar type performing similar function group together to form a **tissue**, more than one type of tissues form **organs**, different organs form **organ systems** and organ systems form an **organism**. In unicellular organisms, such as amoeba, a single cell performs all functions of life. In multicellular organisms like plants and animals, different groups of cells perform different functions. A **tissue** is a group of cells (similar in structure) that work together to perform a specific function. The formation of different types of tissues leads to the division of labour, which increases the efficiency of the body and enables it to carry out complex life processes. For example, in animals, muscle tissue enables movement and nervous tissue carries messages to different parts of the body. In plants, conducting tissues, such as xylem transports water and minerals, while phloem transports food.

3.1 Why are Plant and Animal Tissues Different?

In Chapter 2, Cell: The Building Block of Life, you compared plant and animal cells, and studied the major differences between them. Most plants are fixed in one place and do not move from place to place like animals. They need support to stay firm and upright. Plant cells have a cell wall that provides rigidity and strength. In general, animals can move (although some, such as sponges, are immobile). Without a rigid cell wall, animal cells can change shape easily. This cellular flexibility eventually helps make their bodies suitable for locomotion.

Another major difference between plants and animals is their mode of nutrition. Animals have tissues that help them digest food obtained from different food sources, while plants have tissues that help them utilise solar energy for synthesising the food components through photosynthesis. Plants and animals have distinct tissues for transporting food and water to different parts of the body. The growth patterns in plants and animals also vary because the tissues responsible for growth differ in structure and function. In this chapter, we will learn how the structures of plant and animal tissues relate to their specific functions.

Meet a Scientist

B. G. L. Swamy was a renowned Indian botanist known for his contributions to the area of plant morphology and anatomy. His book, *Hasuru Honnu*, is a popular book in Kannada language. It is a blend of science, satire and culture. The book describes the botanical excursion in the forests of Western Ghats and is a treasure of plant descriptions, utilisation, conservation practices, botanical folklores and myths. The book won the Kendra Sahitya Akademi Award in 1978.

3.2 Tissues for Growth in Plants

You must have observed that a small seedling grows into a tall tree, roots grow deep into the soil, stems become thicker with time and grass grows again after being eaten by grazing animals. Which tissues are responsible for these changes?

Plants grow in different ways —

- increase in **length** (height of stem and depth of roots),
- increase in **girth** (thickness of stem), and
- **regrowth** after cutting the branches or grazing by animals.

This growth require actively dividing cells that together form a tissue called a meristematic tissue.

Let us explore different kinds of meristematic tissues.

3.2.1. Apical meristem — How do plants grow in length?

Let us study the growth of roots in an onion bulb.

(a) Jar A (b) Jar B

Fig. 3.1: Experimental set-up to observe the growth of roots

Activity 3.1: Let us design experiments

1. Take two glass jars or couplin jars and fill them with water.
2. Now, take two onion bulbs and place one in each jar, as shown in Fig. 3.1.
3. Observe the growth of roots in both bulbs for a few days.
4. Measure the length of roots on days 1, 2 and 3.
5. On day 3, cut the root tips of the onion bulb in Jar B by about 1 cm. After this, observe the growth of roots in both the jars, measure their lengths

for four more days (day 4 onwards), and record your observations in Table 3.1.

Table 3.1: Experimental data

Experimental Jars	Length of onion root (cm) from the base of the bulb						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
A							
B							

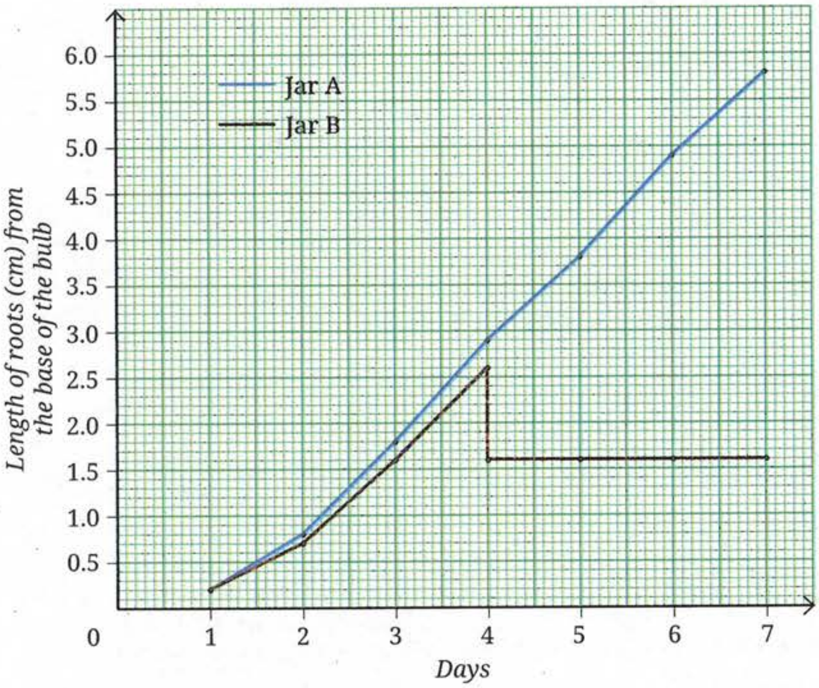


Fig. 3.2: Growth of onion roots

What trend do you **observe** in the data you recorded in Table 3.1? Are your observations similar to those presented in the graphical representation (Fig. 3.2)? What do you infer?

- Roots in Jar A continue to grow in length.
- Roots in Jar B stop growing after the tips are cut.

This shows that roots grow only from their tips. The tips consist of cells which divide continuously.

You may recall observing mitosis in onion root tips in Chapter 2, Cell: The Building Block of Life. This observation confirms that root tips contain actively dividing cells. Similarly, shoot tips also contain actively dividing cells that help the shoots to grow in length. Thus, we conclude that plants have growth zones at the tips of their roots and shoots, called the **apical meristems**, which help the plants grow in length (Fig. 3.3).

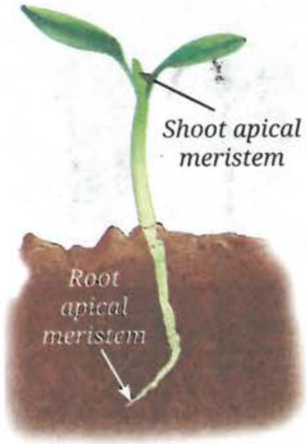


Fig. 3.3: Location of apical meristem in a sapling

3.2.2 Lateral meristem — How do plants grow in girth?

Look at your surroundings. You must have observed that the stems of dicot plants not only grow in length but also increase in diameter or girth over time. What causes this increase in girth? One possible explanation may be the activity of meristematic tissues. If you have visited a timber yard or observed the cut trunk of a tree, you may have noticed several ring-like patterns on the cut surface of the wood (Fig. 3.4). These are annual growth rings. Some annual rings are wide and some are narrow, reflecting the favourable or unfavourable growth conditions during a particular year. By counting these annual rings, scientists can estimate the age of a tree and also understand the climatic conditions under which it grew.

Fig. 3.4: T.S. of a tree trunk showing annual growth rings

The increase in girth occurs due to the presence of actively dividing cells arranged in a ring in the stem. These cells divide and produce new cells inside and outside in a concentric manner, leading to an increase in diameter of stem. This meristematic tissue is called the **lateral meristem**.

Fig. 3.5: New branches arising from the node of a stem

3.2.3 Intercalary meristem—How do plants grow after being cut?

We have learnt that meristematic tissues are present at the tips of roots and shoots. What do you think happens to the growth of the plant if the tip of a young stem is cut? The stem stops growing in length but new branches arise from the the nodes of stem (Fig. 3.5). The intercalary meristem is located at the base of internode or just above the node. The node is point on plant stem where branches or leaves arise. The part of stem between the two nodes is called **internode**. You may also have observed that when the hedge around a garden is cut, after sometime more branches appear again, giving the hedge a bushy appearance. Grass also appear after sometime being mowed (Fig. 3.6) and/or grazed by animals. This happens because of the presence of intercalary meristem at the nodes of its stem. These meristematic tissues are called **intercalary meristems**.

Fig. 3.6: Lawn mowing

Thus, plants have three types of meristematic tissues — apical, lateral and intercalary. The apical meristem, located at the root and shoot tips, increases its length. The lateral meristem located along the circumference of stems increases girth. The intercalary meristem located at the base of certain plants, such as grasses, helps them regenerate after cutting. Together, these meristems account for growth in length, girth and branching in plants.

The cells of the meristematic tissues are small, have thin cell walls, a large and prominent nucleus, and dense cytoplasm with many organelles. Vacuoles are generally absent and the cells are tightly packed with little or no intercellular space. These characteristics of meristematic tissue allow them continuous and rapid cell division. Why do you think that the cell of meristematic tissues lack vacuoles?

Due to continuous cell division, meristematic tissue adds new cells to the plant body. Some of the newly formed cells remain meristematic while others lose the ability to divide. The cells that loose the ability to divide undergo changes in structure and function, and become **permanent tissues**. These cells become specialised to perform specific functions, such as support, transport or storage. This process, by which meristematic tissue becomes specialised to perform specific functions, is called **differentiation**. Meristemetic tissue becomes permanent by the process of differentiation.

3.2.4 Permanent tissues

Examine the Transverse Section(s) (T.S.) of the root and/or stem, and/or the Vertical Section (V.S.) of the leaf of any herbaceous plant under a microscope. The internal structure of a T.S. of a sunflower stem as seen under a microscope is shown in Fig. 3.7. What do you observe? Are all the cells similar in shape and size? How many different types of tissues can you **identify**? What differences do you notice among them? What might be

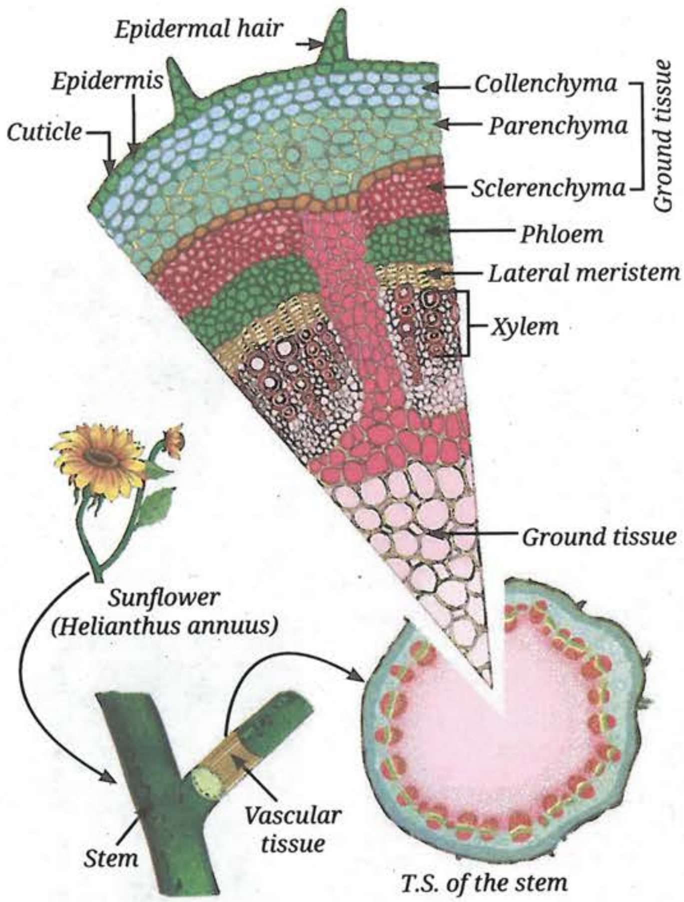


Fig. 3.7: Internal structure of a sunflower stem

the reason for the presence of different types of cells and tissues? You can see that different groups of cells are present and each tissue is specialised to perform a specific function. These are **permanent tissues**. Permanent tissues can be simple (composed of only one type of cell) or complex (composed of more than one types of cells).

Observe the types of tissues given in Fig. 3.7 based on pointers provided as follows:

(i) Protective tissue—Epidermis

What protects plants from mechanical injury, water loss, harmful microorganisms and extreme environmental conditions?

The **epidermis** forms the outermost layer of the plant body. It consists of a tightly packed, single layer of flat and rectangular cells. It protects all parts of the plants. These cells are covered with a waxy layer of cutin called **cuticle**. In some plants, living in very dry habitat, the epidemis may be covered by a thick layer of cuticle to reduce the water loss in the process of transpiration by stomata. The cuticle also provides protection against mechenical injury and invasion by prasites. In many plants, hair-like projections arise from epidermal cells. In roots, these projections are called root hair, which increase the surface area for absorption of water and minerals from the soil. In leaves, the epidermis contains pores called **stomata**, which apart from gaseous exchange helps in transpiration, i.e., evaporation of water vapours through stomata. Thus, transpiration helps in water transportation by creating a transpiration pull in xylem. Transpiration also helps in elimination of wastes from the plant body.

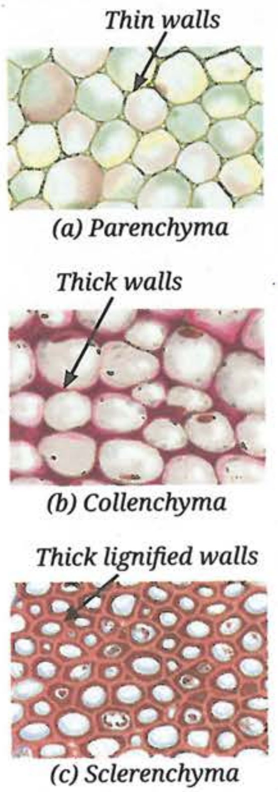


Fig. 3.8: Various types of simple permanent tissues

(ii) Supporting tissue—Simple permanent tissues

What keeps a plant upright? Why does a fresh twig bend but a dry twig break? Why are seed coats hard and how do aquatic plants float? These functions are carried out by supporting tissues. There are three types of supporting tissues or simple permanent tissues—parenchyma, collenchyma and sclerenchyma. Each differs in structure and performs supporting functions.

a. Parenchyma

Parenchyma consists of living cells with thin walls (Fig. 3.8a). These cells are loosely packed with intercellular spaces. Parenchyma mainly stores food but also performs photosynthesis in the green parts of the plants. In aquatic plants, specialised parenchyma forms air spaces, which help them float.

b. Collenchyma

Collenchyma consists of living cells with unevenly thickened corners due to pectin (a chemical that gives flexibility like rubber) deposition (Fig. 3.8b).

This tissue provides support and flexibility, allowing parts of the plant like stems and tendrils to bend without breaking.

c. Sclerenchyma

Sclerenchyma cells have thick walls (Fig. 3.8c) due to deposition of lignin, making them hard and strong (forms the woody structure). Most of these cells are dead. This tissue is found in stems, leaf veins, and hard coverings of seeds and nuts, such as coconut husk and walnut shell.

(iii) Conducting tissues — Complex permanent tissues

How does water reach the leaves of tall trees? How does food prepared in leaves reach other parts of the plant?

Plants have specialised conducting tissues called **xylem** and **phloem**, together known as **complex permanent tissues**, because they are made up of different types of cells working together. Xylem (Fig. 3.9a) is the tissue that transports water and minerals from the roots to other parts of the plant. It also provides strength to the plant. Xylem consists of tracheids, vessels, xylem parenchyma and xylem fibres. Tracheids and vessels are tubular and thick-walled. Xylem parenchyma are the only living component of xylem while trachieds, vessels, and xylem fibres are primarily sclerenchymatous. Unlike the xylem, phloem is mostly made up of living cells (Fig. 3.9b). It consists of sieve tubes, companion cells, phloem parenchyma and phloem fibres. Some cells are long and tubular, joined end to end by perforated walls. These cells form **sieve tubes**. Sieve tubes transport food from leaves to other parts of the plant. The cellular functions of the sieve tube cells are regulated by **companion cells**. Companion cells are specialised parenchyma cells. Main function of companion cells is to monitor loading and unloading of sugars in sieve tubes. Phloem parenchyma store food materials, and resin, tannins and latex. The sieve tubes are also supported by phloem fibres which are primarily schlerenchymatous and provide strength.

So far, we have studied different types of plant tissues based on their functions — protection, support and conduction. In a plant body, these tissues do not work alone. They are organised together into larger groups called **tissue systems**.

Plant tissues are organised into three tissue systems (Fig. 3.10) —

1. **Dermal tissue system:** This forms the outer covering of the plant. It protects the inner parts and reduces water loss.

Pause and Ponder

1. You may have noticed that fibres of coconut husk are hard and brittle, whereas the leaf stalks of coriander are soft and flexible. Find out the reason.

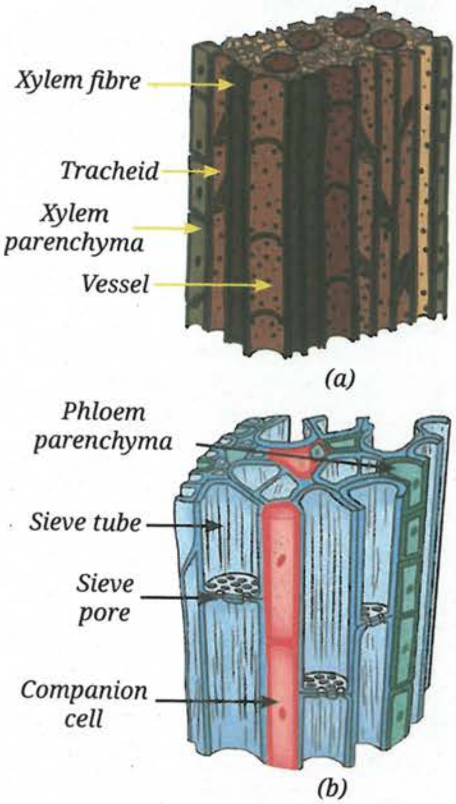


Fig. 3.9: Vascular tissue: (a) xylem, and (b) phloem

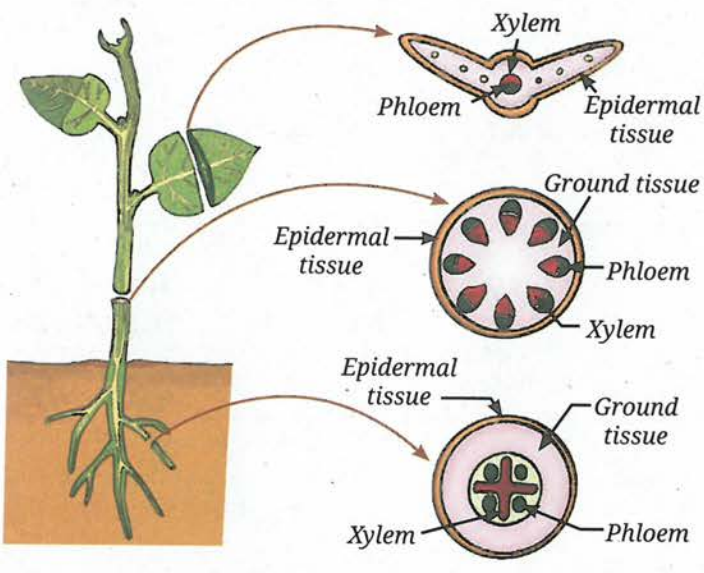


Fig. 3.10: Tissue systems in plants

Meet the Scientists

Sipra Guha Mukherjee in collaboration with **S. C. Maheshwari** made a breakthrough discovery in the area of plant tissue culture. Their research led to the development of a complete plant through anther culture, using an artificial nutrient medium under controlled laboratory conditions. This pioneering work greatly contributed to crop improvement and brought significant progress in modern agriculture.

Ready to Go Beyond

In young plants, the outer protective l[illegible] single-lay[illegible]mis. As plant[illegible] grow older, some cells below the epidermis of the stem develop the ability to divide, act as lateral meristematic cells and form the cork cambium. The division of cork cambium cells gives rise to cork cells. Cork cells are dead, compactly arranged, and contain a substance which makes them impermeable to water and gases. This forms the bark of the tree.

2. **Ground tissue system:** This forms the main body of a plant between the dermal and conducting tissues. It includes parenchyma, collenchyma and sclerenchyma.
3. **Vascular tissue system:** This consists of conducting tissues — xylem and phloem.

Pause and Ponder

2. Why do you think that a thick cuticle on the outer wall of epidermis is advantageous for a plant living in the desert but disadvantageous for a plant living underwater?
3. Once water is absorbed by plant roots, it has to travel against gravity through xylem. How do the 'dead' cells of the xylem work together with the living cells of leaves at the top to keep the water moving?
4. What do you think will happen if there were no stomata in the epidermis of the stem or leaves?

3.3 Animal Tissues

Like plants, animal cells also group together and specialised in performing different functions. These groups of similar cells form animal tissues. Let us perform a few simple activities —

- Blink your eyes quickly.
- Clench and open your fist.
- Take a deep breath.
- Touch something warm or cold.

Now think, which tissue helps you move? Which tissue enables you to sense heat or cold? Which tissue allows oxygen to enter the blood? Which tissue holds the body together so that the skin does not fall off?

Many such questions can be asked but the answers lie in the diversity of animal tissues, which are specially adapted to perform different functions. It is interesting to understand how the structure of an animal tissue suits its specific function.

Let us explore different kinds of animal tissues. Each tissue performs a specific function.

3.3.1 Epithelial tissues — Structure and functions

Epithelial tissue forms the outer covering of the body (skin) and also lines the internal organs, such as the mouth, lungs, blood vessels and intestine. It is composed of closely packed cells with very little space between them. This structure prevents the entry of the germs, reduces water loss, and also helps in the absorption, secretion and movement of substances. Different types of epithelial tissues are structurally adapted to perform different functions (Table 3.2).

Study Table 3.2 along with the corresponding diagrams shown in Fig. 3.11 to understand how structure and function of epithelial tissues are related.

Table 3.2: Characteristics of functionally and structurally different epithelial tissues

Function	Structure	Location in the body
Exchange: Helps in rapid diffusion of liquids and gases	Single layer of thin, flat cells (Fig. 3.11a)	Lining of the tissue in the blood vessels and lungs
Protection: Protects underlying tissues from mechanical injury, friction and entry of microbes	Many layers of cells; the outer cells are flat and tightly packed (Fig. 3.11b)	Skin, mouth and oesophagus
Secretion: Production and secretion of mucus, enzymes, hormones, sweat saliva	Cells specialised for producing and releasing substances; may be cuboidal or columnar (Fig. 3.11c)	Salivary glands, sweat glands and stomach lining
Sensory functions: Smell, taste, sound and balance	Specialised receptor cells having hair like cilia (Fig. 3.11d)	Nostrils, taste buds and inner ear
Absorption: Efficient uptake of nutrients, water, etc.	Single layer of tall, pillar-like cells, often with hair-like structure (Fig. 3.11e)	Lining of small intestine

3.3.2 How are various parts connected in our body?

You have read that blood connects different parts of the body by transporting nutrients, gases, hormones, etc. In the same way, bones connect and support the body from head to toe. A tissue that connects and supports other tissues is called a **connective tissue**. Both blood and bones are connective tissues. Though both are connective tissues, they differ in composition and consistency. Blood is fluid, while bone is hard. This difference is due to the matrix, which is watery, soft and jelly-like in blood but hard, solid, and rigid in bones (Fig. 3.12a).

Grade 7 Curiosity Chapter 9

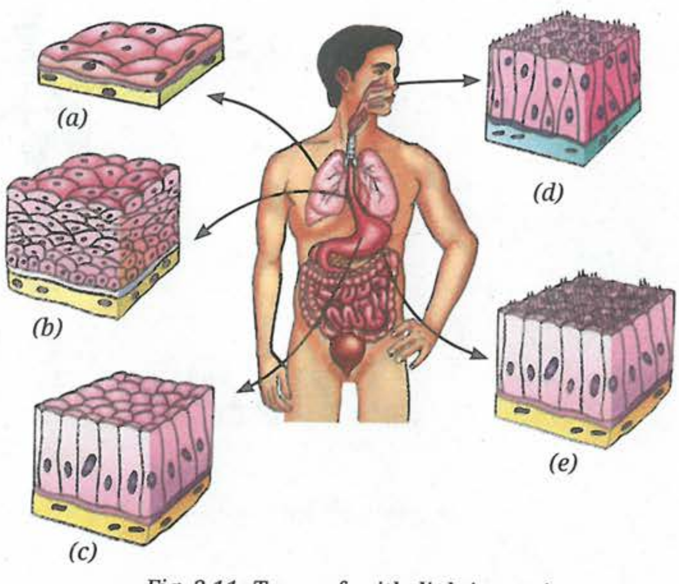


Fig. 3.11: Types of epithelial tissues in different parts of the body

Activity 3.2: Let us understand further

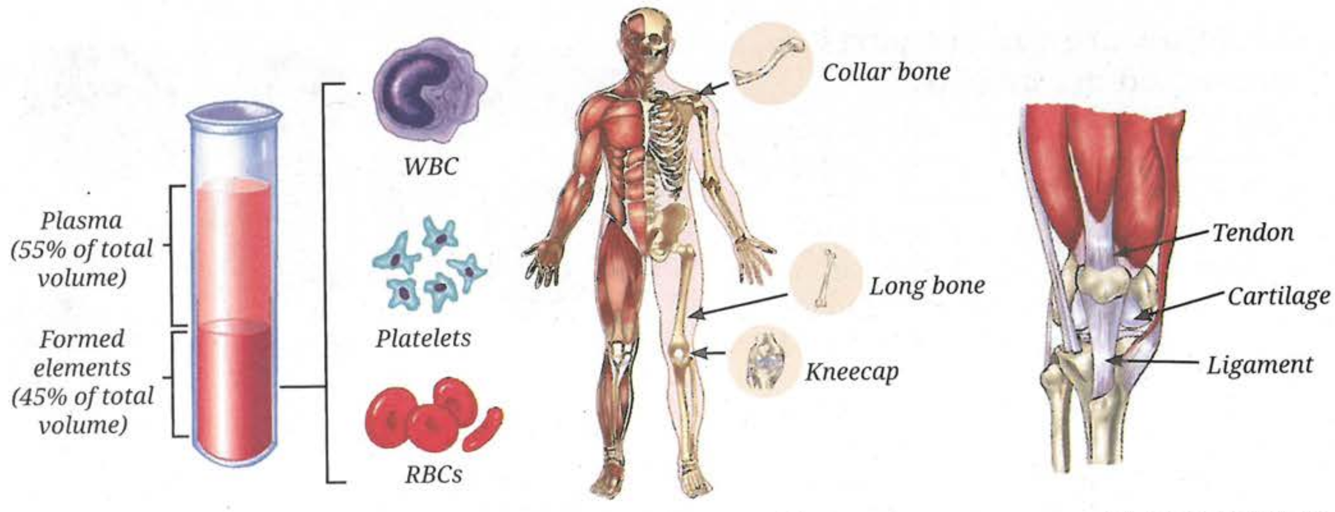
- Recall everyday experiences given in the first column of Table 3.3.
- Write your observations and questions in your notebook.
- **Compare** your observations with the observations given in Table 3.3.

Table 3.3: Your experiences, observations and questions from daily life

Experiences	Observations	Questions
When you get a small cut on your skin	Red blood oozes out from the cut. A clot is formed after some time.	What causes blood to clot?
When you get a skin infection	The area turns red and perhaps slightly swollen. You may have a fever.	
When you exercise or run	You breathe faster. Your face may turn red.	

The everyday experiences mentioned above are related to blood and its components.

1. The red colour of blood is due to haemoglobin, an iron-rich protein in the Red Blood Cells (RBCs). RBCs live for about 4 months and are replaced regularly.
2. Platelets help in blood clotting at the site of the injury.
3. During exercise or running, muscles need more oxygen, so breathing becomes faster and blood flow increases (face appears red).
4. White Blood Cells (WBCs) collect at infected areas, causing pus formation and inflammation (causing redness and swelling, and possible pus formation at the infected area).



(a) Components of blood *(b) Types of bones* *(c) Arrangement of tissues at a joint*

Fig. 3.12: Types of connective tissues

Functions of other connective tissues as experienced through different actions.

Activity 3.3: Let us perform

1. Perform the actions given in Table 3.4.
2. Record your experiences and compare them with the experiences given in Table 3.4.
3. Study their functions and identify the connective tissues (Fig. 3.12).

Table 3.4: Connective tissues

Action	Experience	Function	Identified connective tissue
Touch your elbow gently	A hard and rigid structure	Gives strength, support and protection	Bone (Fig. 3.12b)
Press and fold your ear or gently press your nose and stop	A soft and flexible structure that retains shape again	Provides flexibility and cushions the ends of bones for shock absorption	Cartilage (Fig. 3.12c)
Touch your forearm muscles and wiggle your fingers	Feel movement in the forearm even though fingers are far away	Connects muscle to bone, and thus, brings about movement	Tendon (Fig. 3.12c)
Sit on a chair and move your leg upwards till your knee allows	The joint does not go beyond a limit	Connects bone to bone and provides stability, limits movement, and helps prevent dislocation	Ligament (Fig. 3.12c)

Bones have a rigid matrix containing calcium and phosphorus compounds, giving them strength and rigidity. In contrast, cartilage has a soft, jelly-like matrix, and provides flexibility and cushioning. Other connective tissues include tendons and ligaments. Tendons connect muscles to bones, while ligaments connect bones to bones and prevent excessive movement (Fig. 3.12c).

3.3.3 Can we control movement in our body?

Some movements are under our conscious control, such as running, writing or lifting objects. These are called **voluntary movements** and are carried out by skeletal muscles (Fig. 3.13), which are attached to the skeleton. They are made up of bundles of long, cylindrical cells called **muscle fibres**, which are unbranched, multinucleate (having many nuclei) and striated (showing light and dark bands).

Are there involuntary movements in the body? Yes, many body movements occur automatically without conscious control, for example the movement of food in the intestine and the beating of the heart. These are called **involuntary movements**. The muscles responsible for these

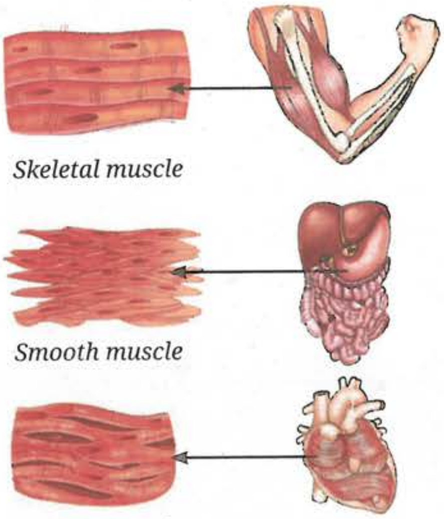


Fig. 3.13: Different types of muscles

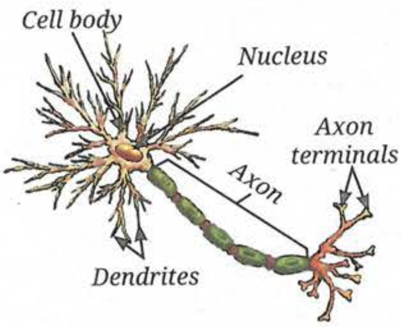


Fig. 3.14: Structure of a neuron

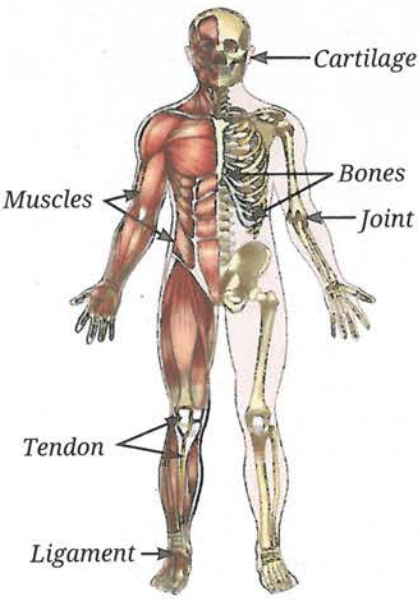


Fig. 3.15: Musculoskeletal system in human body

movements include **smooth muscles** (Fig. 3.13), which are found in organs like the stomach and intestines. Their cells are spindle-shaped, have a single nucleus and lack striations. They help in slow, continuous movements like digestion.

The **cardiac muscles** (Fig. 3.13) are found only in the heart. Their fibres are cylindrical and branched with a single nucleus, and have faint striations. Cardiac muscles work tirelessly and rhythmically, enabling the heart to beat throughout life without fatigue.

3.3.4 How does the body sense, communicate and respond?

Have you noticed how quickly you pull your hand away from something hot, or how you remember the lyrics of a song learned long ago? These actions are controlled by **nervous tissue**, which forms the body's control and coordination network. The brain acts as the control centre; coordinating activities, memory and responses across the body. Muscles, both voluntary and involuntary, cannot function independently. They receive instructions from the nervous tissue. For example, during exercise, the brain signals the heart to beat faster to meet the body's increased oxygen demand.

The cells of nervous tissue are called **neurons** (Fig. 3.14) or nerve cells, which are specialised to receive, process and transmit messages. Each neuron has three main parts — the cell body, which contains the nucleus and controls cell activities; **dendrites**, which receive signals from other neurons; and an **axon**, a long fibre that carries messages from the cell and ends at axon terminals. The axon terminals transmit the messages to other cells.

3.4 The Musculoskeletal System

The **musculoskeletal system** (Fig. 3.15) is made up of bones, muscles, joints, cartilage, tendons and ligaments. This system helps us stand upright, move, maintain posture and protect delicate organs. The musculoskeletal system functions under the control of the nervous system. Muscles pull on bones to produce movement. They are attached to bones by strong, flexible bands called **tendons** (Fig. 3.15). When a muscle contracts, the tendon transmits this force to the bone, resulting in movement at a joint. Have you wondered how much of your body weight comes from bones? On an average, the adult human skeleton makes up about 12 – 15 per cent of body weight, though this can vary with age, gender and body composition.

Activity 3.4: Let us investigate

What percentage of total body weight comes from bones and muscles?

1. Step on a weighing scale and record your total body weight.
2. Use online references or health resources to find average bone and muscle mass percentage for your age, gender, and an Indian body type (these may vary by ethnicity). For example, on average, adult males have about 40 – 50 per cent muscle, and adult females have ~30 – 40 per cent muscle, although bone mass is about 12 – 15 per cent for all adults.
3. Multiply your total body weight by the bone percentage and muscle percentage to **estimate** the weight of your bones and muscles.
4. Record the estimated bone weight and muscle weight, and compare them with your total body weight.
5. Compare your findings with those of your classmates and calculate the class average.

Discuss why do bone and muscle mass differ between individuals, and how do they contribute to the overall body weight?

3.4.1 The musculoskeletal system in action

Activity 3.5: Let us observe

Move different parts of your body and observe what movement(s) it can make.

Table 3.5: Different types of movements our body can make

Body parts	Complete rotation	Partial rotation	Bending	Turning, side-raising, up-down or any other movement
Elbow	No	No	Yes	
Shoulder				
Knee				
Neck				
Fingers				
Toes				
Wrist				

You may have noticed that some parts of our body can move easily in many directions, while others move only in a single direction. Why does this happen? The difference is due to the types of joints present. A joint is a junction between two or more bones. Joints allow movement but they cannot move the bones on their own. So, what actually causes the bones to move?

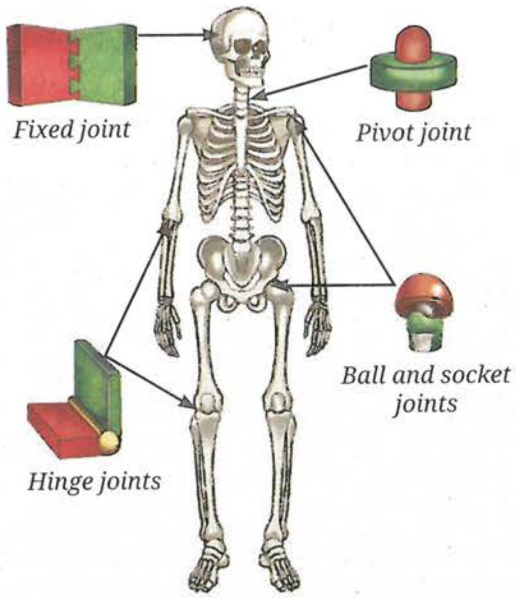


Fig. 3.16: Types of joints

3.5 Types of Joints

3.5.1 Ball and socket joint

The shoulder joint allows free movement of the arm (Table 3.5). This is because the rounded top of the upper arm bone fits into a shallow hollow of the shoulder bone, forming the **ball and socket joint** (Fig. 3.16). Together with the collarbone, the shoulder forms the shoulder girdle, which connects the arm to the skeleton. This joint allows forward, backwards, sideways and circular movements.

3.5.2 Hinge joint

Unlike the shoulder, the elbow bends and straightens in one direction only like a door hinge (Table 3.5). This type of joint is called a **hinge joint**. A similar hinge joint is present in the knee, where a small bone called the kneecap protects the joint.

3.5.3 Pivot joint

Now, try shaking your head 'no.' Place your hand at the back of your neck and feel the gentle movement. How does the neck move so freely? The skull is connected to the backbone through a **pivot joint**, which allows the head to move side to side like a doorknob turning in its socket.

3.5.4 Fixed joints

The skull is a hard case of flat bones joined together to protect the brain, eyes and ears. The bones of the skull are connected by **fixed joints**, which means the bones of the skull cannot move. This keeps the brain safe even when the body moves.

Ready to Go Beyond

Stem cells in the bone marrow are special cells that can divide and make new cells. In a bone marrow transplant, stem cells from a healthy person are given to patients who have blood cancers like Leukemia or disorders, such as Thalassemia.

Pause and Ponder

5. Look at the picture given below (Fig. 3.17). Carefully observe the various poses of classical and folk dances of India. Can you identify which joints are involved? Also, what type of movement each joint allows?

Fig. 3.17: Poses of classical and folk dances of India

3.6 Skeletal System

The skeletal system consists of a framework of bones that provides strength and protects delicate internal organs. It includes the skull, vertebral column and rib cage. From the base of the skull, it extends a flexible column called the **backbone** or **vertebral column** (spine), made up of a series of small bones called **vertebrae**. It supports the body and helps us stand upright. Between each vertebra is a cartilage disc, which acts as a cushion and allows flexibility, so we can bend and twist without injuring the internal spinal cord.

Can you feel the bones under your chest? These are your ribs. You have 12 pairs of ribs and together they form the rib cage. The rib cage acts like a protective cage to protect vital organs, such as the heart and lungs. But you may wonder, "How can such a strong cage move? And why does it need to move?". The ribs are attached to the spine at the back and to the breast bone (sternum) in the front. They are joined by flexible cartilage. This flexibility allows the rib cage to expand and contract during breathing. This movement increases and decreases space in the chest, allowing air to move in and out of the lungs. Injury to the ribs can make breathing painful and difficult.

Bridging Science and Society

Yoga, described in ancient Indian texts includes physical postures, breathing and meditation. Research shows it improves flexibility, posture and breathing, reduces stress, and helps prevent lifestyle diseases. Every year, 21st June is observed as the International Yoga Day to promote role of Yoga in health and well-being.

Maintaining correct posture, proper nutrition, regular exercise and yoga keeps our bones strong, muscles fit, joints flexible, and protects the body from stiffness.

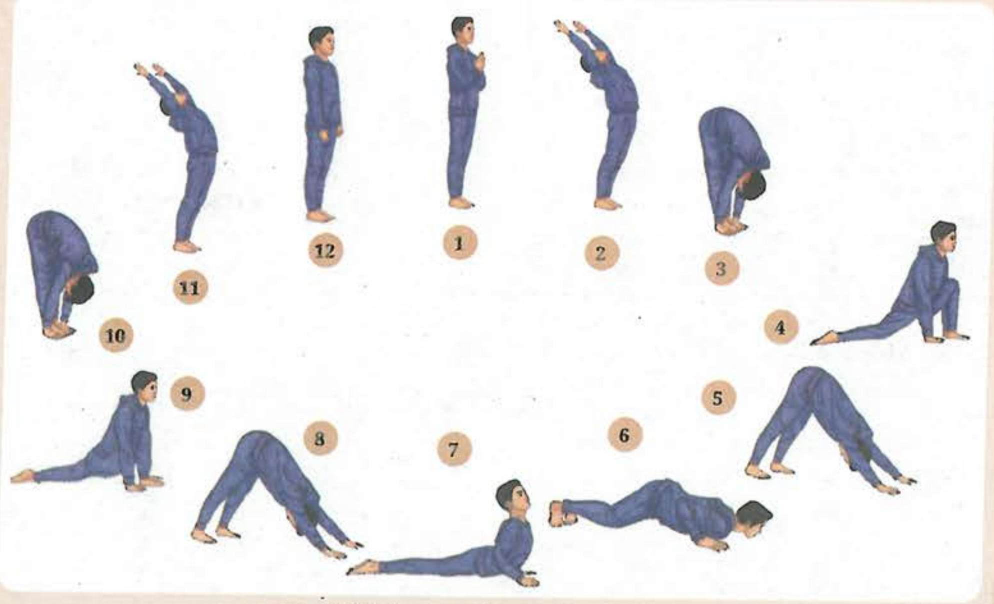


Fig. 3.18: Poses of Surya Namaskar

Think as a Scientist

From one cell to an organism: Totipotency

In 1958, F. C. Steward demonstrated that even single cells from vascular phloem of carrot retain the ability to regenerate whole plants. He was the first person to do so!

He and his team performed an experiment using the phloem cells of carrot. He grew these cells in a nutrient medium containing simple sugars and hormones under appropriate conditions. He observed that these phloem cells divided to form a mass of cells, which gradually divided and differentiated into a complete plant.

It shows that cells of phloem first dedifferentiated (cells regain the ability to divide) to form an undifferentiated mass of unspecialised cells. These, when grown in appropriate conditions, supplemented with nutrients and growth chemicals, further divided and redifferentiated to form roots, shoot, and eventually the complete plant. Thus, some mature plant cells have the ability to undifferentiate, divide and redifferentiate to develop into a new plant under specific conditions. This is known as totipotency and such cells are totipotent cells. This is similar to the ability of a zygote to divide and differentiate into an entire organism.

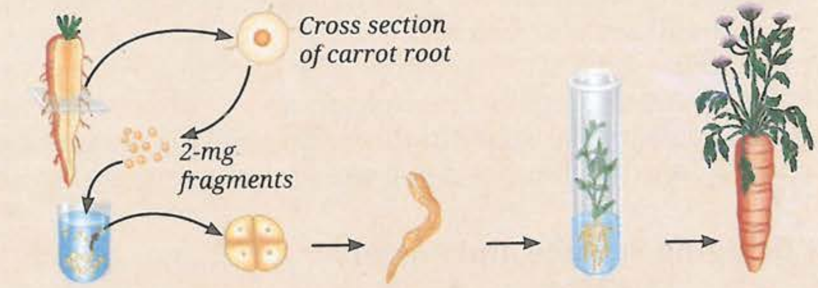


Fig. 3.19: Regeneration of a carrot plant

In his experiment on phloem cells of carrot, F. C. Steward used different combinations of nutrients and other factors, and obtained the following results.

Table 3.6: Effect of light, air and nutrient medium on growth of the cultured plant cells

Conditions		Composition of nutrient medium	Increase in fresh weight (mg) of the cells from intial weight
Light	Air		
✓	×	Solid medium + nutrients	reduced
✓	✓	Liquid medium + nutrients	20% increased
×	✓	Liquid medium + nutrients	reduced

Based upon Table 3.6, think about these questions:

(a) What do you **conclude** about the characteristics of phloem cells of carrot?

(b) In which of the three combinations would you obtain the highest and lowest biomass? What could be the possible reason(s) for this observation?

(c) Will you get the same results if you culture animal cells instead of carrot cells?

(d) Think and mention any two commercial applications of the study above.

Bridging Science and Society

Fig. 3.20: Crown gall disease

In nature, plant pathologists have observed a disease in plants called crown gall disease (Fig. 3.20). In this disease, tumour-like swellings develop on the stems due to rapid and uncontrolled cell division. The disease is caused by a bacterium called *Agrobacterium tumefaciens*.

Instead of only trying to cure this disease, scientists studied how a bacterium transfers its genetic material into plant cells. This knowledge was later used in plant tissue culture and genetic engineering. Today, *Agrobacterium* is used as a tool to introduce useful genes into plants for the production of valuable phytochemicals, improved crops and disease-resistant varieties.

At a Glance

- Tissues are groups of similar cells that work together to perform specific functions.
- Different tissues coordinate with one another to perform life processes in plants and animals.
- Plant tissues are broadly classified into meristematic and permanent tissues, depending on their ability to divide.
- Functionally, plant tissues can be categorised as protecting tissue, supporting tissue and conducting tissue.
- Permanent tissues may be simple (made-up of one type of cell) or complex (made-up of more than one type of cell).
- Simple permanent tissues include parenchyma, collenchyma and schlerenchyma.
- Complex permanent tissues include xylem and phloem that transport water and food respectively to all parts of the plant.
- Animal tissues are mainly of four types; epithelial, connective, muscular and nervous tissues.
- Epithelial tissue forms the outer covering of the body or protective lining to internal organs to provide protection and other functions.
- Connective tissue connects and supports various organs and tissues of the body.
- Muscular tissue produces voluntary and involuntary movements for locomotion, and other movements in the body.
- Nervous tissue consists of neurons to receive and transmit impulses, and helps regulate body activities.
- Skeletal system protects organs and provides support.
- In our body, movement occurs by the coordination of muscles and bones (musculoskeletal system), under the control of the nervous system.

Revise, Reflect, Refine

1. Meristematic tissues divide repeatedly. What property of their cells allows them to do this?
   (i) They have thick walls for protection.
   (ii) They contain large vacuoles that store nutrients.
   (iii) They have thin walls, dense cytoplasm and large prominent nucleus.
   (iv) They are functionally differentiated cells.
2. If a plant is unable to transport food from leaves to roots which tissue is malfunctioning?
   (i) Xylem
   (ii) Phloem
   (iii) Epidermis
   (iv) Sclerenchyma
3. Why are the epithelial tissues that line an animal's internal organs usually only one or a few cells thick?
   (i) To store food efficiently.
   (ii) To provide maximum strength.
   (iii) To allow quick exchange of materials across them.
   (iv) To reduce friction.

Fig. 3.21

4. You can perform these two jumps (Fig. 3.21):
   Straight-leg jump — keep knees and ankles stiff.
   Normal jump — bend knees and ankles naturally.
   How did your ankle, knee and hip positions differ between the two jumps?
5. Which type of joint is involved when you bend your knees and ankles?
   (i) Ball and socket
   (ii) Hinge
   (iii) Pivot
6. In each of the following cases (A, B, C and D), choose the correct option as given below:
   (i) Both (A) and (R) are true, and (R) is the correct explanation of (A).
   (ii) Both (A) and (R) are true, but (R) is not the correct explanation of (A).
   (iii) (A) is true, but (R) is false.
   (iv) (A) is false, but (R) is true.

   A. Assertion: Epithelium is well-suited for gas exchange in the lungs.
   Reason: It consists of multiple layers of tall cells that slow down diffusion.

   B. Assertion: Cardiac muscle can contract continuously without fatigue.
   Reason: Cardiac muscle cells have a high number of mitochondria and an abundant blood supply.

C. Assertion: Tendons connect bone to bone and allow joint movement.
Reason: Tendons are made of tough connective tissue that transmits force from muscle to bone.

D. Assertion: In a hinge joint, movement occurs primarily in one plane.
Reason: The bone ends are shaped to allow sliding in all directions.

7. Plot a graph between the age of a tree (in years) on the x-axis and the diameter of the tree (in cm) along with the number of annual rings formed over time on the y-axis, using the data given in the Table 3.7.

Table 3.7: Data related to the age of a teak tree, and corresponding increase in the diameter of stem and number of annual rings

S. No.	Age of the teak tree (Years)	DBH (Diameter at Breast Height) of tree (cm)	Number of annual rings formed
1.	5	4	5
2.	10	8	10
3.	20	24	20
4.	25	28	25
5.	30	32	30
6.	40	40	40

(i) Analyse the graph in terms of the diameter of the stem over time and share the interpretation.
(ii) What is the relation between the diameter of the teak tree to the annual rings formed?
(iii) Which specialised tissue is responsible for the girth of the stem and where is it located?

8. In a forest, it was observed that one of the trees was severely debarked by an elephant to meet its food requirements, as the bark is a rich source of nutrients (Fig. 3.22). Based on your learning, answer the following:

Fig. 3.22

(i) Which function(s) of the tree is/are hampered by debarking?
(ii) Which plant tissue would be affected by further damage to the tree trunk even after debarking?
(iii) Which function of the tree would be hampered if the tissues beneath the bark were severely damaged?
(iv) What assumptions are you making to answer the questions above? How would the answer change if your assumptions are also changed?

9. Aamrapali observed that a young mango sapling's stem bends flexibly during monsoon winds and does not break. Which tissue is responsible for this flexibility? Predict and provide your explanation of the impact if the existing tissue was replaced by sclerenchyma.
10. Sohan designed an experiment for the regeneration of sugarcane, where he used cuttings to grow sugarcane. He used two types of cuttings, type 'A' and type 'B' (Fig. 3.23). After a few weeks, type 'B' cuttings sprouted and developed into sugarcane plants, whereas the type 'A' cuttings did not sprout.

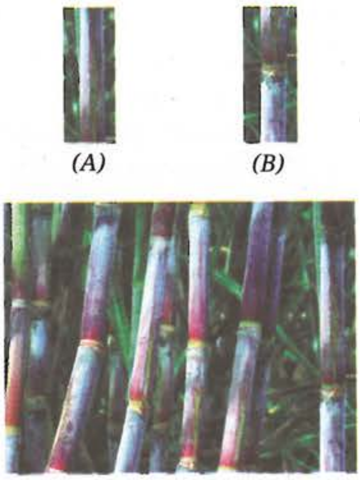


Fig. 3.23

    (i) Why were the type 'B' cuttings able to grow as sugarcane but type 'A' could not?
    (ii) What difference was present in type 'B' compared to type 'A'?
    (iii) What observation or measurement was made to determine whether this change had an effect?
    (iv) What parameters should be kept the same for both types of cuttings to ensure a fair comparison?
11. During the discussion in class, Rohan gives a statement that, "A tissue is a group of similar cells performing similar functions". But Rajiv counter argues that, "this is true in case of simple tissues but little different in case of complex tissues". Provide your explanation in view of the discussion in class.
12. Coconut husk fibres are used for mats which are tough and fibrous. Which tissue has structural features suitable for providing this strength? Explain why living parenchyma couldn't serve the same purpose.
13. Vibha claims to her friend Neha that, "Meristematic cells are located only at the root and shoot apices". What do you think about this statement? What question can Neha ask Vibha to help her understand further if the statement is incorrect?
14. A plant cell and an animal cell are of the same size.
    (i) Which cell will have a larger vacuole? Give reasons.
    (ii) What assumptions are you making to answer the question above?
15. A textbook states, "Each plant tissue performs only one specific function". What questions would you ask to critically examine the correctness of this statement? What examples of tissues would you take to find out the answers to these questions?

The Journey Beyond

- Visit a doctor and find out what happens in ligament rupture, cartilage rupture and fracture of bones. How can we reduce the risk by changing our lifestyle and nutritional balance?
- Perform the following activity.
  (i) Sit with your feet flat on the floor.
  (ii) Place your fingers on the back of your ankle just above the heel (Fig. 3.24).
  (iii) Point your toes down and up, and you will feel the tendon moving.

  Tendons are designed to withstand huge pulling forces. Try exploring other tendons in your body around the different joints.

Fig. 3.24

- Reflect on any of the physical practices you are familiar with, such as yoga, kabaddi, etc. How would it support bone and muscle health?
- Reflect on any gardening methods you know, such as pruning, grafting, irrigation or crop rotation. How does each practice support the healthy functioning of plant tissues like meristems, conducting tissues or supporting tissues?
- Turn a nature walk into a research project.
  (i) Observe different leaves and study their adaptations for various environments, such as desert, very moist or aquatic habitats.
  (ii) Consult an elder community resource persons about their knowledge on different plant leaves, such as leaves that remain fresh for a long time, repel water or deter insects. Find out their traditional uses, such as making plates, preparing cooling wraps or functioning as insect repellents.
- Study various dance forms of different tribal communities across the country. Each student learn and experience at least five steps. Observe the joint movements involved in performing these steps and then develop a dance or drama on the concept of joint movements. Perform this at the school's annual function so that students from different grades can learn from it.

Fig. 3.25

The Quest Continues...

Will it be possible to obtain a complete animal from an animal cell like plants? If yes, what would be the advantages and challenges of this development?

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Chapter

4

Describing Motion Around Us

Think It Over

- How much distance should we maintain from the truck ahead to avoid a collision if it suddenly applies the brakes?
- Does this distance depend upon the speed with which we are moving?

Everything in nature is in motion, from massive astronomical objects to subatomic particles. We have a wide variety of motion in nature, such as flitting butterflies, slithering snakes, hopping hares, galloping horses, tendrils of climbers twinning around a support, closing of flytraps, dancing dust particles in a sunbeam, smoke particles moving in air, rising and falling of ocean tides, and gathering clouds.

Isn't motion in nature wonderful? But how do we study the wide variety of complex motions around us? As you have read in the first chapter, to explore a complex phenomenon, scientists first study it in its idealised simplified forms. Such types of motion are linear, circular and oscillatory about which you learnt in earlier grades. In this chapter, you will learn more about linear motion (motion in a straight line) and uniform circular motion.

Grade 6 Curiosity Chapter 5

Earlier, you learnt about some physical quantities, such as distance, time and speed. Now, you will learn

Grade 7 Curiosity Chapter 8

about some more physical quantities, such as displacement, average velocity and average acceleration. You will also learn to describe motion not only in words, but also with numbers, equations and graphs.

4.1 Motion in a Straight Line

You have learnt that when an object moves in a straight line, its motion is called linear motion. It can also be called **motion in a straight line**. It is the simplest kind of motion. Have you noticed it around you, such as children in a swimming race, a vertically falling ball, a car moving along a straight stretch of a highway or a train moving on a straight track (Fig. 4.1)?

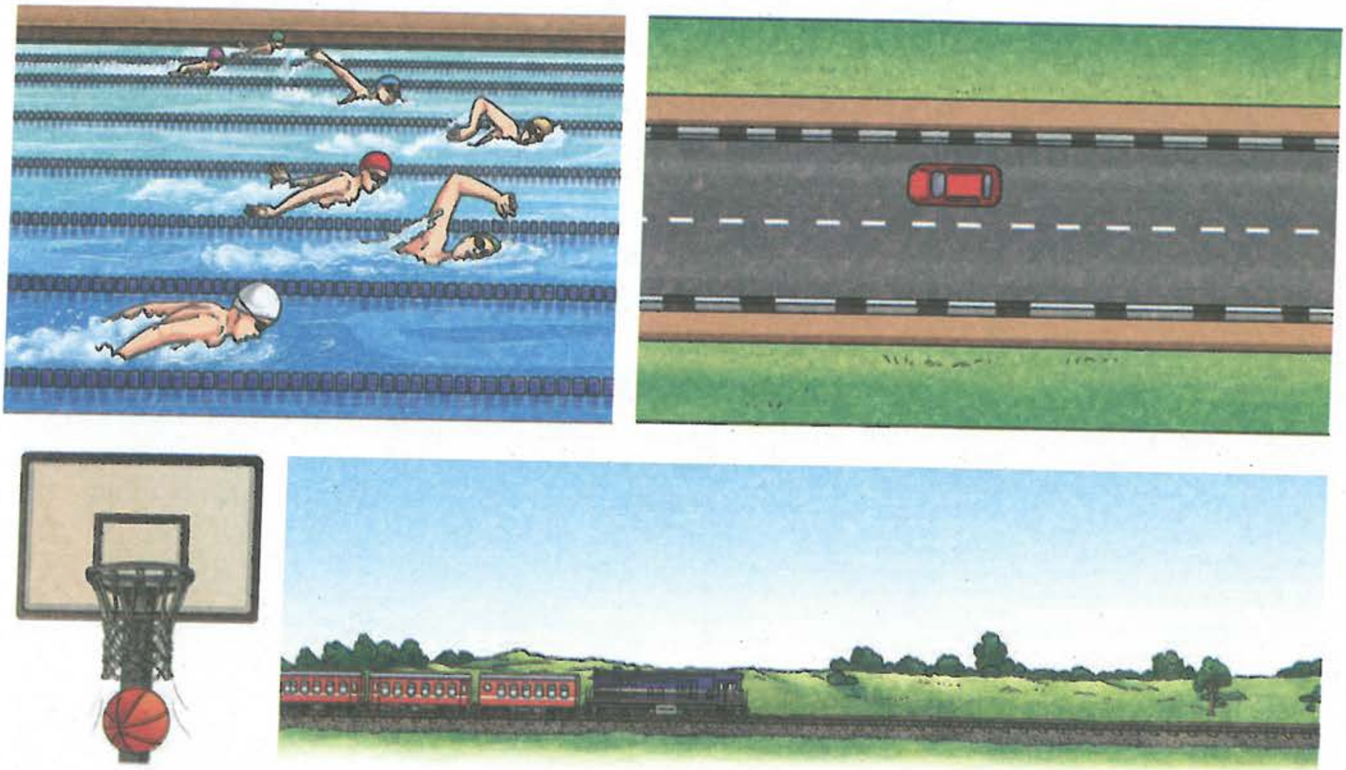


Fig. 4.1: Objects in a straight line motion

To discuss about the motion of an object, you first need to describe its position at various instants of time.

4.1.1 Describing position

Grade 6 Curiosity Chapter 5

How do we describe the position of an object? For that, as you learnt earlier, we first need to specify a fixed point as the **reference point**. The distance and direction of the object with respect to the reference point, at any instant of time, describes the **position of the object** at that instant of time. Note that apart from the distance, we also specify the direction from the reference point in which the object is located to describe its position. But when do we say that an object is in motion? If the position of the object with respect to the reference point changes with time, the object is said to be **in motion**. On the other hand, the object is said to be **at rest** if its position with respect to the reference point does not change with time.

Fig. 4.2: An athlete running on a straight track

Let us take the example of an athlete running on a straight track (Fig. 4.2).

To describe the position of Neena, an athlete, let us take her starting point as the reference point. As shown in Fig. 4.3, let us make a straight line with distances marked on it and mark the reference point on it as the **origin** 'O'. The athlete starts running from O, and her positions at two instants of time are marked by points B and A.

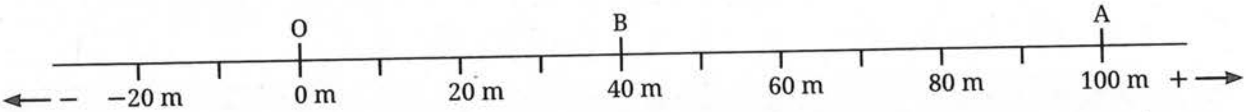


Fig. 4.3: Reference point and positions of the athlete at different instants of time on a straight line

Note

An instant of time and a time interval are not the same thing. An **instant of time** is a single reading of clock at a given point of time. Whereas, a **time interval** is the time duration between two instants of time, i.e., between two readings of a clock.

To describe the position of an object, we also need to specify its direction. For the object moving in a straight line, the object can move only in one of the two directions — forward and backward. Thus, the direction is represented by plus (+) and minus (–) signs as shown in Fig. 4.3. Positions to the right of the reference point O are generally taken as positive and to the left of O as negative (Fig. 4.3).

4.1.2 Distance travelled and displacement

Suppose an athlete starts running from point O at time $t = 0$ s, reaches point B at $t = 4$ s, then reaches point A at $t = 10$ s, then runs back along the same path till point B reaching there at $t = 16$ s (Fig. 4.4). How much is the total **distance travelled** by the athlete between the starting and stopping positions? The total distance travelled is OA + AB = 100 m + 60 m = 160 m.

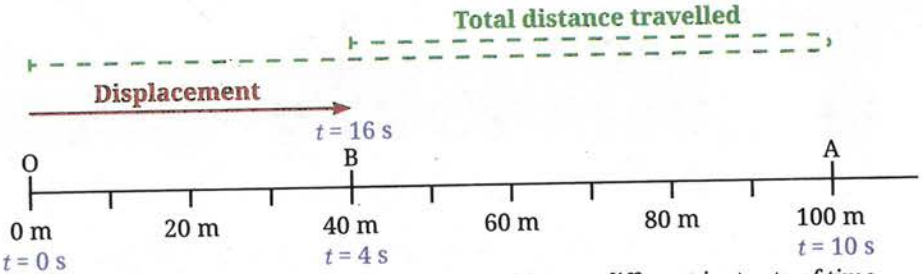


Fig. 4.4: Reference point and positions of athlete at different instants of time

Ready to Go Beyond

Physical quantities which can be specified by just their numerical value are called scalars. Physical quantities which require specifying both the direction and magnitude are called vectors. You will learn about these in higher grades.

Next Level Up

Let us now think about the distance between the starting and the stopping positions of the athlete. It is OB = 40 m, which is different from the total distance travelled by the athlete. So, let us now define another quantity — displacement.

Displacement is the net change in the position of an object between the two given instants of time. A complete description of physical quantities like displacement requires specifying both a direction and its numerical value (with units). The numerical value (with units) of such a physical quantity is called its **magnitude**. The magnitude of displacement is the distance between the object's positions at the two instants. The direction of displacement is specified from the position at the first instant towards the position at the second instant. To describe the total distance travelled, only the numerical value (with units) is required, not the direction of motion. The **SI unit** for both is the **metre (m)**.

For example, in Fig. 4.4, between $t = 0$ s and $t = 16$ s, the total distance travelled by the athlete is 160 m, but her displacement is 40 m in the positive direction. We find that between these two instants, the total distance travelled and the magnitude of displacement are not equal. Can these quantities ever be equal?

Note

For motion in a straight line, the total distance travelled and the magnitude of displacement are equal if the object moves without turning back, i.e., if it moves in one direction.

Activity 4.1: Let us analyse

1. As shown in Fig. 4.5, a ball is thrown vertically upwards from O. It moves up straight till B and then falls back to O. Can this be considered a motion in a straight line?
2. For this motion, fill up the values in Table 4.1.

Table 4.1: Distance travelled and displacement of the ball

S. No.	Position	Total distance travelled by the ball from O till that position	Displacement of the ball from O till that position
1.	O	0 cm	0 cm
2.	A	40 cm	40 cm in upward direction
3.	B		
4.	C		
5.	O		

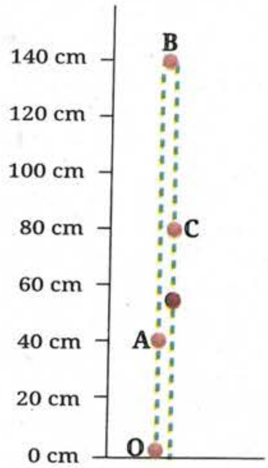


Fig. 4.5: A ball in vertical motion (two separate lines are shown only for clarity; in reality, the object goes up and falls back in the same straight line)

3. **Analyse** the data filled in Table 4.1 and choose which of the following is true for displacement:
   (i) It is never zero.
   (ii) Its magnitude can be greater than the total distance travelled.
   (iii) Its magnitude is less than or equal to the total distance travelled.
   (iv) Its magnitude is less than the total distance travelled in all cases.

Pause and Ponder

1. In the example of an athlete running back and forth on a straight track (Fig. 4.4), when will the displacement of the athlete be zero? What will be the total distance travelled in that case?
2. Fuel used up in a vehicle depends on which of the following? Justify your answer.
   (i) Total distance travelled
   (ii) Displacement
3. A ball rolls down an inclined track as shown in Fig. 4.6. Is its motion, a straight line motion? Assuming the starting point of the ball (O) to be the origin, can its motion from O to D be depicted using a horizontal line as shown in Fig. 4.3? Are the values of total distance travelled and magnitude of displacement from O equal or different at positions A, B, C and D?

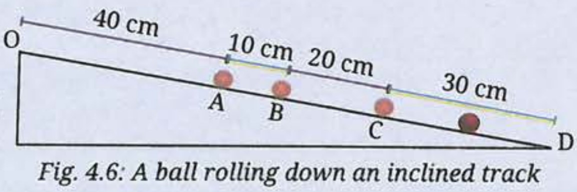


Fig. 4.6: A ball rolling down an inclined track

Motion, i.e., a change in the position of an object, can be described in terms of the total distance travelled by the object and its displacement. But how can you describe how fast or slow an object is moving?

4.1.3 Average speed and average velocity

Grade 7 Curiosity Chapter 8

You have learnt about average speed in an earlier grade. It tells us how fast or slow an object moves. The **average speed** of an object is the total distance travelled divided by the time interval during which this distance is covered. Thus,

$$\text{average speed} = \frac{\text{total distance travelled}}{\text{time interval}} \qquad (4.1)$$

Since distance travelled has no direction (but only a numerical value), the average speed, which is calculated from distance travelled, also has no direction but only a numerical value.

If an object moving in a straight line travels equal distances in equal intervals of time (for all possible choices of time intervals), it is said to be in uniform motion in a straight line. In this case, the object moves at a constant speed. On the other hand, if the object travels unequal distances in equal intervals of time, then it is in non-uniform motion in a straight line. In this case, the object moves with increasing speed or decreasing speed, or a combination of both. If the distances travelled in the successive intervals of times are increasing, its speed is increasing.

India's Scientific Contributions

The concept that an object's speed is the distance travelled divided by the time taken is well-established, dating back to ancient times even in India, as seen in the treatise *Aryabhatiya* (5th century CE). The following problem, based on this concept, is from a comprehensive mathematical text, the *Ganitakaumudi* (14th century CE).

Example 4.1: Consider two postmen. They start walking towards each other from a distance of 210 *yojanas* (*Yojana* is a unit of distance used in ancient India). One travels 9 *yojanas* per day and the other covers 5 *yojanas* per day. Can you determine in how many days they will meet each other?

Answer:

Total of distance covered by each postman in one day = 9 *yojanas* + 5 *yojanas* = 14 *yojanas.*

To meet with each other, the postmen need to cover 210 *yojanas* together.

Time taken by them to cover 210 *yojanas* together $= \frac{210}{14} = 15$ days.

So, both postmen will meet each other after 15 days.

(In 15 days, first postman will cover 135 *yojanas* and the second postman will cover 75 *yojanas*).

The speed tells us how fast an object is moving but it provides no information about the direction of motion. There are many situations where along with the speed, you also need to know the direction of motion to get a complete picture, particularly in case of complicated real-world motions.

Let us define another physical quantity, average velocity, which describes how fast the position of an object is changing and in which direction.

The **average velocity** of an object in a time interval is the change in the position (or displacement) divided by the time interval in which the change in position (or displacement) occurs. Thus,

$$\text{average velocity} = \frac{\text{change in position}}{\text{time interval}} = \frac{\text{displacement}}{\text{time interval}} \qquad (4.2a)$$

If we represent average velocity by v_{av}, displacement by s and time interval by t, then Eq. (4.2a) can be written as

$$v_{av} = \frac{s}{t} \qquad (4.2b)$$

To express the average velocity, you need to specify its magnitude as well as the direction. How do we associate direction with velocity when the motion is in a straight line? The direction of the velocity is the same as the direction of displacement and is indicated by a '+' or '–' sign.

The **SI unit of average speed** and **average velocity** are the same. It is **metre per second** which is represented by **m s^{-1}** or **m/s**. It is also commonly measured in kilometre per hour (km h^{-1}).

To describe how fast or slow a change in a physical quantity happens, we use the idea of a rate of change. The ratio of change in one quantity to the corresponding change in time is called the **rate of change**. To calculate average velocity, we find the ratio of change in position to the time taken (Eq. 4.2a). So, we can say that average velocity is the average rate of change of position of an object with respect to time.

Note

For motion in a straight line, the average speed and the magnitude of average velocity in a time interval are equal if the object moves in one direction.

Example 4.2: Sarang takes 50 seconds to swim from one end to the other end and back in the swimming pool shown in Fig. 4.7. Find his average speed and average velocity within the time interval of 50 s.

Answer:

Total distance travelled by Sarang in 50 s = 50 m

displacement of Sarang in 50 s = 0 m

$$\text{average speed} = \frac{\text{total distance travelled}}{\text{time interval}} = \frac{50\ \text{m}}{50\ \text{s}} = 1\ \text{m s}^{-1}$$

$$\text{average velocity} = \frac{\text{displacement}}{\text{time interval}} = \frac{0\ \text{m}}{50\ \text{s}} = 0\ \text{m s}^{-1}$$

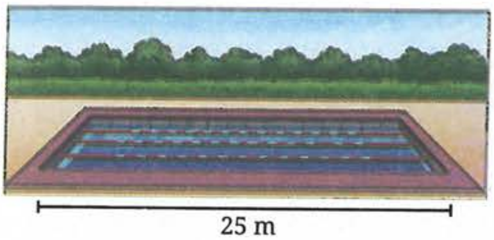


Fig. 4.7: Swimming pool

During the 50 s time interval, the average speed of Sarang is approximately 1 m s^{-1} while his average velocity is 0 m s^{-1}.

Pause and Ponder

4. During a family road trip, you drive 200 km north in three hours. Afterwards, you drive 200 km south in two hours. Find the average speed and average velocity for your entire trip.
5. Under what condition(s) is the
   (i) magnitude of average velocity of an object equal to its average speed?
   (ii) magnitude of average velocity of an object zero while its average speed is not zero?

Threads of Curiosity

The reading of the speedometer of a vehicle is nearly (but not exactly) the same as the magnitude of the velocity at an instant while the direction of tyres gives the direction of velocity at that instant.

The average velocity of an object over a large time interval may differ from its velocity at a particular instant. Throughout this chapter, we will use the term 'velocity' to mean the velocity of an object at a particular instant.

Ready to Go Beyond

What we simply called 'velocity at an instant' is known as 'instantaneous velocity'. As the time interval around an instant is made progressively smaller (Eqn. 4.2b), the change in average velocity gets smaller and smaller. When the time interval becomes infinitesimally small, the average value of velocity approaches a fixed value called the instantaneous velocity. You will learn more about this physical quantity in higher grades. Next Level Up

The velocity of an object can be constant or it can change with time. How can we express the change in velocity of an object?

4.1.4 Average acceleration

When you sit in a vehicle and it suddenly moves from rest, you feel a noticeable jolt. Similarly, when the vehicle is in motion and suddenly stops, you experience a jolt. These occurrences capture the feeling of the change in velocity. You can find the change in velocity if you know the velocity at two different instants of time.

Let us now learn another physical quantity, the average acceleration. The **average acceleration** of an object over a time interval is the change in its velocity divided by the time interval. That is,

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{time interval}} \quad (4.3a)$$

$$\text{average acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time interval}} \quad (4.3b)$$

If the velocity of an object changes from an initial value u at time t_1 to the final value v at time t_2, the average acceleration a is,

$$a = \frac{v - u}{t_2 - t_1} \quad (4.3c)$$

The **SI unit of average acceleration** is **m s^{-2}** or **m/s^2**. Like displacement and velocity, we need to specify the magnitude as well as the direction of acceleration. For motion in a straight line, if the magnitude of velocity is increasing in a given time interval, the average acceleration is in the direction of velocity (Fig. 4.8). Whereas, the average acceleration is opposite to the direction of velocity if the magnitude of velocity is decreasing.

Fig. 4.8: Direction of average acceleration when magnitude of velocity is (a) increasing, and (b) decreasing

The average acceleration can result from change in the magnitude of velocity or change in its direction, or both. Later in Section 4.4, we will discuss an example of acceleration resulting from only the change of direction of the motion while the speed remains constant.

Activity 4.2: Let us calculate

1. The magnitude of average acceleration of cars is generally specified as the time taken by the car to go from 0 km h^{-1} to 100 km h^{-1}. Look it up on the internet and find this time for various cars, and record those in Table 4.2.
2. Calculate the magnitude of average acceleration for each car.

Table 4.2: The magnitude of average acceleration in a time interval

Car type	Time interval during which the speed goes from 0 to 100 km h^{-1}	Magnitude of average acceleration (m s^{-2})

Example 4.3: A bus is moving on a long straight highway (Fig. 4.9) with a velocity of 36 km h^{-1}. The driver presses the accelerator for a time interval of 10 s and velocity of the bus increases to 54 km h^{-1}. For some time, the bus moves at a constant velocity. Then, the driver notices an obstacle on the road ahead and presses the brake. The bus comes to a stop in a time interval of 5 s. Find the average acceleration in the two time intervals, (i) when the accelerator was pressed, and (ii) when the brakes were pressed.

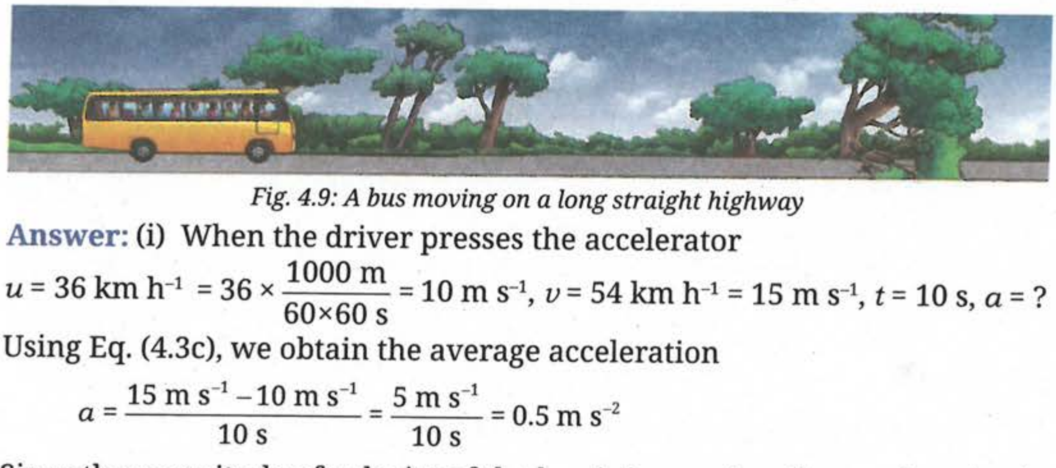


Fig. 4.9: A bus moving on a long straight highway

Answer: (i) When the driver presses the accelerator

$u = 36 \text{ km h}^{-1} = 36 \times \dfrac{1000 \text{ m}}{60\times60 \text{ s}} = 10 \text{ m s}^{-1}$, $v = 54 \text{ km h}^{-1} = 15 \text{ m s}^{-1}$, $t = 10$ s, $a = ?$

Using Eq. (4.3c), we obtain the average acceleration

$$a = \frac{15 \text{ m s}^{-1} - 10 \text{ m s}^{-1}}{10 \text{ s}} = \frac{5 \text{ m s}^{-1}}{10 \text{ s}} = 0.5 \text{ m s}^{-2}$$

Since the magnitude of velocity of the bus is increasing, the acceleration is acting in the direction of velocity.

(ii) When the driver presses the brake

$u = 54 \text{ km h}^{-1} = 15 \text{ m s}^{-1}$, $v = 0 \text{ m s}^{-1}$, $t = 5$ s, $a = ?$

Using Eq. (4.3c) again, we obtain

$$a = \frac{0 \text{ m s}^{-1} - 15 \text{ m s}^{-1}}{5 \text{ s}} = \frac{-15 \text{ m s}^{-1}}{5 \text{ s}} = -3 \text{ m s}^{-2}$$

The minus sign indicates that the acceleration is acting opposite to the direction of velocity (since the magnitude of velocity of the bus is decreasing).

Note
An object can be moving very fast and yet have zero acceleration. Acceleration depends not on how fast an object is moving, but on how quickly its velocity is changing. For example, a bus moving on a straight highway at constant velocity has zero acceleration, even though its velocity may be high.

Note

In this chapter, we will consider only the cases where the acceleration is constant.

The average acceleration during different time intervals can either be constant or changing. For an object moving in a straight line in the same direction, if the magnitude of its velocity increases or decreases by equal amounts in equal intervals of time (for all possible choices of time intervals), the acceleration of the object is constant.

Grade 8 Curiosity Chapter 5

Example 4.4: As we learnt earlier, when an object is dropped from a height, it takes a straight vertical path downwards before touching the ground. While coming down, the velocity of the object increases as shown in Fig. 4.10 at different instants. Find the magnitude of the average acceleration of the object in every successive interval of a second. Is the average acceleration constant across all intervals? What is the direction of this average acceleration?

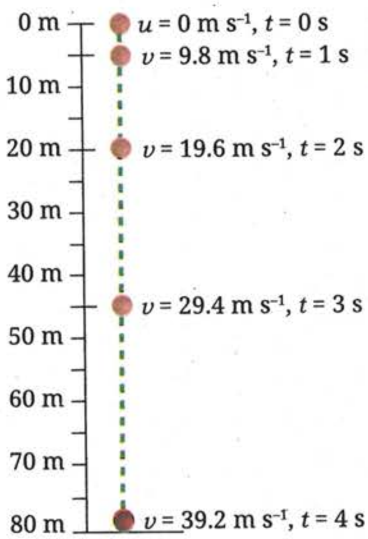


Fig. 4.10: An object dropped from a height

Answer: The magnitude of the average acceleration in every successive interval is

average acceleration between 0 s and 1 s $= \dfrac{(9.8-0)\ \text{m s}^{-1}}{(1-0)\ \text{s}} = 9.8\ \text{m s}^{-2}$

average acceleration between 1 s and 2 s $= \dfrac{(19.6-9.8)\ \text{m s}^{-1}}{(2-1)\ \text{s}} = 9.8\ \text{m s}^{-2}$

average acceleration between 2 s and 3 s $= \dfrac{(29.4-19.6)\ \text{m s}^{-1}}{(3-2)\ \text{s}} = 9.8\ \text{m s}^{-2}$

average acceleration between 3 s and 4 s $= \dfrac{(39.2-29.4)\ \text{m s}^{-1}}{(4-3)\ \text{s}} = 9.8\ \text{m s}^{-2}$

We note that the average acceleration is constant and equal to 9.8 m s^{-2}. As the velocity is increasing in the direction of motion, the acceleration is in the direction of motion. This acceleration is called the acceleration due to gravitational force by the Earth and is denoted by g.

Did you notice that in Fig. 4.5, we chose the origin at the ground level while in Fig. 4.10, we chose the origin at the point from where the object is dropped? In this example, we use down side as positive. We can choose the origin and positive direction as per our convenience. However, once chosen, it should not be changed while solving a problem.

Just like we can specify the velocity of an object at an instant, we can specify the acceleration of an object at an instant.

Ready to Go Beyond

Similar to 'velocity at an instant', 'acceleration at an instant' is known as 'instantaneous acceleration'. You will learn more about it in higher grades.

Next Level Up

4.2 Graphical Representation of Motion

One useful way of representing motion can be a graphical representation. It provides a visual representation of how position, velocity and acceleration change with time. Such graphs help in comparing the motion of two objects, in calculating physical quantities, or in identifying whether the motion is uniform or non-uniform.

Grade 8 Ganita Prakash Part II Chapter 5

As you have learnt in Mathematics, graphs come in various forms, each suited to different types of data representation. To describe motion, we will use graphs to show dependence of one physical quantity, such as position, velocity or acceleration, on another quantity, such as time. Let us learn to plot and interpret line graphs for motion.

Note

All the graphs that we will discuss in this chapter are for motion in a straight line in one direction only. In this special case, distance travelled and magnitude of displacement are equal, and speed and magnitude of velocity are also equal. If position is zero at time zero, then the position-time graph is same as the distance-time graph and the velocity-time graph is same as the speed-time graph.

4.2.1 Plotting graph

To plot a graph, let us use the data given in Table 4.3 for a vehicle moving on a straight road.

Table 4.3: Positions of vehicle at different instants of time

Time	0 s	1 s	2 s	3 s	4 s	5 s	6 s
Position	0 m	20 m	40 m	60 m	80 m	100 m	120 m

Activity 4.3: Let us plot a graph

1. Take a sheet of graph paper. This paper is pre-divided into small squares (Fig. 4.11a), making it easier to plot data accurately.
2. On the graph paper, draw two lines perpendicular to each other as shown in Fig. 4.11a. Their point of intersection is known as origin O. Mark the horizontal line as OX. It is known as the x-axis. Similarly, mark the vertical line as OY. It is called the y-axis.
3. Refer to Table 4.3. We need to decide which quantity (time or position) to be shown along each axis. For the data we have (Table 4.3), we will show time along the x-axis and position along the y-axis.
4. **Determine** a suitable scale for each quantity to represent it on the graph paper. We need to choose scales that allow us to represent the data effectively and conveniently while utilising the available space. The scale can be

   x-axis: 5 divisions = 1 s

   y-axis: 5 divisions = 20 m
5. Use the chosen scale to mark values for time (1 s, 2 s, ...) along the x-axis from the origin. Similarly, mark values for position (20 m, 40 m, ...) along the y-axis (Fig. 4.11b).
6. Begin plotting points on the graph paper to represent each set of time and position values from Table 4.3.
   (i) Table 4.3 shows that at time 0 s, the position is also 0 m. The point corresponding to this set of values on the graph will therefore be the origin itself.
   (ii) At 1 s, the position of vehicle is at 20 m. To mark these values, look for the point that represents 1 s on the x-axis. Draw a line parallel to the y-axis at

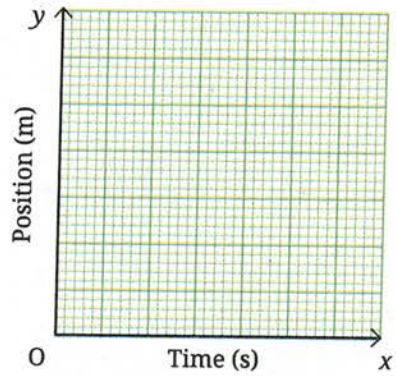


Fig. 4.11(a): Marking origin, x and y axes on graph paper

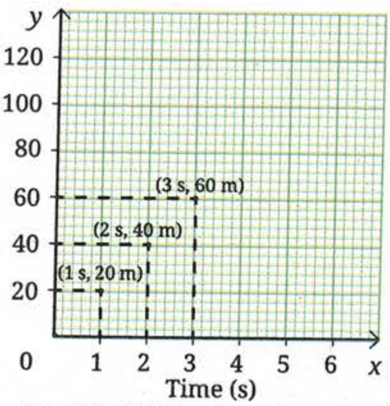


Fig. 4.11(b): Plotting points on the graph

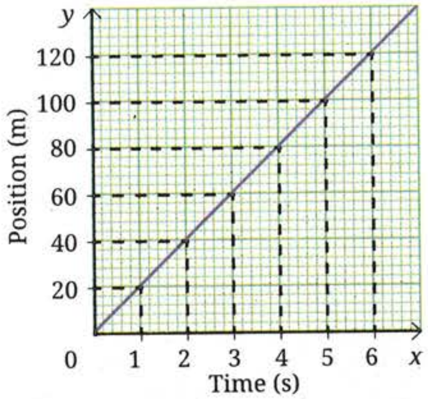


Fig. 4.11(c): Making a graph

this point. Then, draw a line parallel to the x-axis from the point corresponding to distance 20 m on the y-axis. The point where these two lines intersect represents the position 20 m at time t = 1 s on the graph (Fig. 4.11b).

(iii) Similarly, plot on the graph paper all points corresponding to positions of the vehicle at different instants of time.

7. Once all points are plotted, connect them to create the position-time graph for the vehicle's motion (Fig. 4.11c). It is a straight line for the data given in Table 4.3.

This was an example of plotting a position-time graph. Similar procedure can be used to plot the other graphs which you will be learning ahead.

Note

Remember, a graph is not a route map. It does not show the route but how the position of the object changes with time with respect to the origin.

Ready to Go Beyond

The intermediate points represent possible values for position of vehicle at intermediate times. They are correct if vehicle is moving with a constant speed.

Example 4.5: For a vehicle starting from rest and speeding up, the data for position and time are given in Table 4.4. Plot the position-time graph corresponding to it.

Table 4.4: Positions of vehicle at different instants of time

Time	Position
0 s	0 m
2 s	1 m
4 s	4 m
6 s	9 m
8 s	16 m
10 s	25 m
12 s	36 m

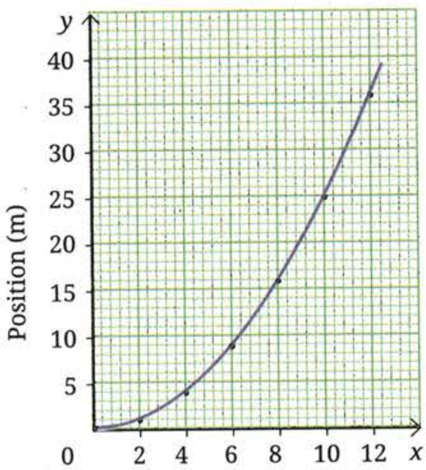


Fig. 4.12: Position-time graph of the vehicle

Answer:

Choosing the scale to be

x-axis: 5 divisions = 2 s

y-axis: 5 divisions = 5 m

and following the procedure of Activity 4.3, all points corresponding to positions of the vehicle at different instants of time are marked. Unlike Fig. 4.11c, the points do not fall on a straight line. The points can be joined by a curve as shown in Fig. 4.12.

Now that you know how to plot a graph from the data given for the motion of an object, let us learn to **interpret** the graphs.

4.2.2 Position-time graphs

The position-time graph represents the motion of object, i.e., the change in its position with time. You have already plotted two position-time graphs (Figs. 4.11c and 4.12). Now, what information can you obtain from these graphs about the motion of the object?

What does the shape of the position-time graph indicate about the nature of motion?

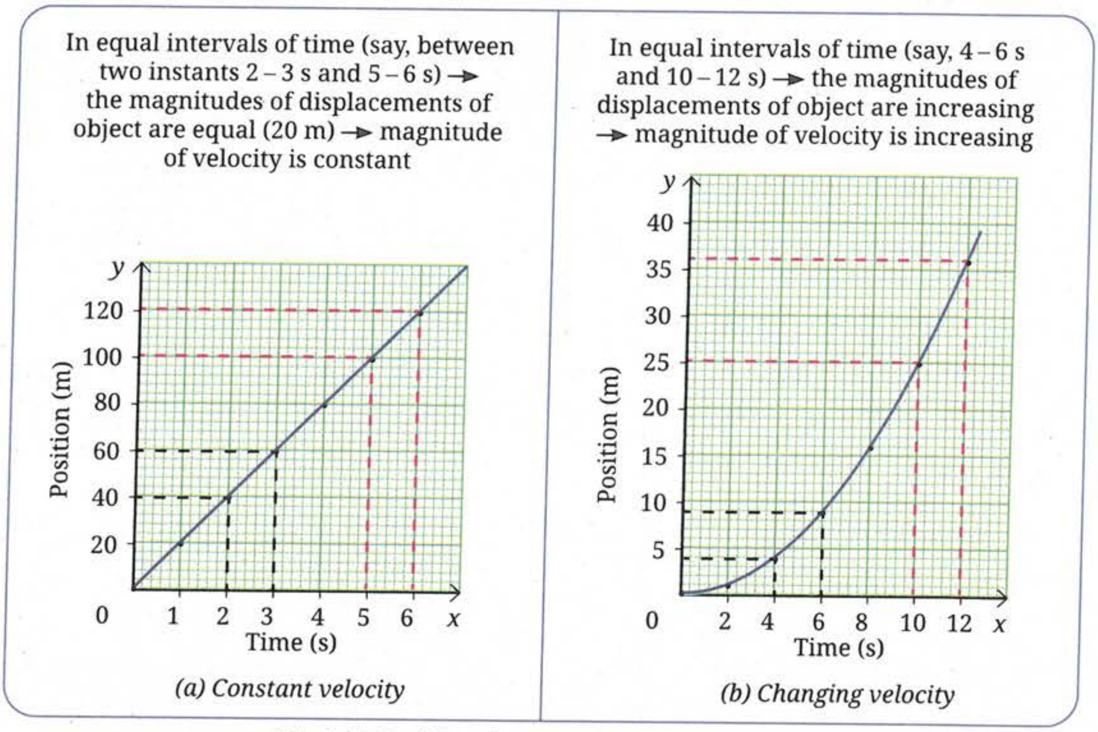


Fig. 4.13: Position-time graph of a moving object

As we can see in Fig. 4.13a, a straight line position-time graph indicates that the object is moving with a constant velocity. On the other hand, a curved position-time graph as in Fig. 4.13b, indicates that the velocity is not constant, and thus, the object is in accelerated motion.

Which physical quantities can be obtained from a position-time graph?

From the position-time graph, you can find the position of an object at each instant of time. Does the graph provide information about any other physical quantity as well? In fact, you can also calculate how fast the position is changing, i.e., the magnitude of velocity of the object. How can you do that?

Activity 4.4: Let us calculate

1. In the position-time graph we plotted (Fig. 4.11c), consider a part (say, AB) of the graph as shown in Fig. 4.14. From A, draw a line parallel to x-axis and another line parallel to Y-axis. Repeat the same from B.
2. Extend the horizontal line from A and a triangle ABC is formed. What do the sides BC and CA of the triangle represent? BC represents the change in position ($s_2 - s_1$), and AC represents the change in time ($t_2 - t_1$).

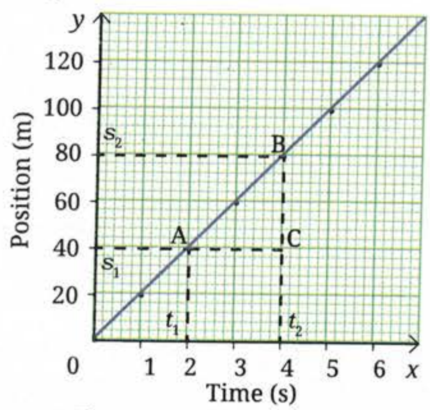


Fig. 4.14: Calculating velocity from a position-time graph

3. As per Eq. (4.2a), by dividing the change in position (BC) by the change in time (CA), you get the average velocity

$$v = \frac{s_2 - s_1}{t_2 - t_1} = \frac{BC}{CA}$$

4. By extracting values of time t_1 and t_2, and distances s_1 and s_2 from the graph, the magnitude of average velocity can be calculated as

$$v = \frac{80\text{ m} - 40\text{ m}}{4\text{ s} - 2\text{ s}} = \frac{40\text{ m}}{2\text{ s}} = 20\text{ m s}^{-1}$$

From a position-time graph, by finding the positions of the object at two instants of time, you can calculate the average velocity by using Eq. (4.2a).

Geometrically, $\frac{BC}{CA}$ is called the slope of line AB connecting initial position A and final position B in Fig. 4.14. The slope of a line is the steepness of the line. The slope of a graph gives information about the rate of change of the quantity shown on y-axis with respect to the quantity shown on x-axis.

Ready to Go Beyond

For the case of a curve, the velocity at any instant can also be calculated geometrically from the position-time graph. You will learn how to do it in higher grades.

Next Level Up

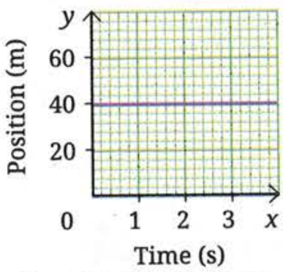


Fig. 4.15: Position-time graph of a vehicle

Example 4.6: What does the graph shown in Fig. 4.15 indicate about the nature of motion of the vehicle?

Answer: The position of the vehicle is 40 m from the origin and is not changing with time. Thus, the vehicle is at rest at 40 m from the origin. A straight line parallel to the time axis on a position-time graph represents a stationary object (In this case, the position-time graph is not the distance-time graph).

Example 4.7: The position-time graphs of two objects A and B are given in Fig. 4.16a. Which object of the magnitude of average velocity is higher?

Answer: By making lines parallel to axes as shown in Fig. 4.16b, it is found that the displacement of object B is more than object A for the same time interval. That is, the slope of line for B is steeper than the slope for line A. Thus, the velocity of B is higher than that of A.

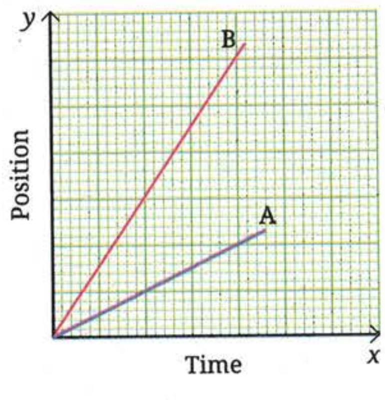


Fig. 4.16(a): Position-time graph of two objects

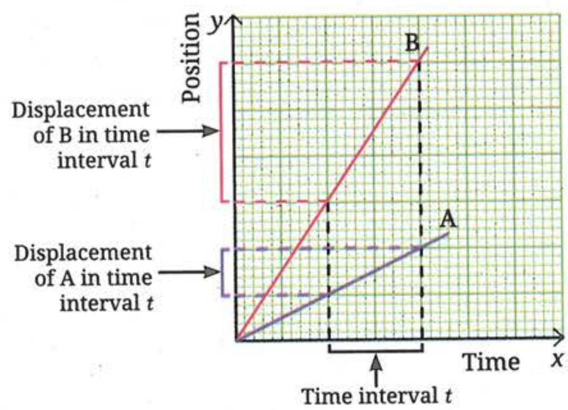


Fig. 4.16(b): Comparing displacement of two objects from position-time graph

4.2.3 Velocity-time graphs

The velocity-time graph of an object in motion represents the change in its velocity with time. In a manner similar to the position-time graph, you can plot velocity-time graphs following the steps of Activity 4.3.

Let us take the example of a car moving in the same direction on a straight stretch of a highway at a steady velocity of 72 km h^{-1} or 20 m s^{-1}. The velocity-time graph corresponding to it is shown in Fig. 4.17a.

Consider another car that starts moving from rest and its velocity increases with time as shown in Table 4.5. The velocity-time graph plotted for this case is shown in Fig. 4.17b.

Consider yet another car moving with a velocity of 15.0 m s^{-1}. Its velocity decreases with time as shown in Table 4.6 and its velocity-time graph is shown in Fig. 4.17c.

Table 4.5: Increasing velocity

Time	Velocity of car
0 s	0 m s^{-1}
5 s	2.5 m s^{-1}
10 s	5.0 m s^{-1}
15 s	7.5 m s^{-1}
20 s	10.0 m s^{-1}
25 s	12.5 m s^{-1}
30 s	15.0 m s^{-1}

Table 4.6: Decreasing velocity

Time	Velocity of car
0 s	15.0 m s^{-1}
5 s	12.5 m s^{-1}
10 s	10.0 m s^{-1}
15 s	7.5 m s^{-1}
20 s	5.0 m s^{-1}
25 s	2.5 m s^{-1}
30 s	0 m s^{-1}

What does the shape of the velocity-time graph indicate about the nature of motion?

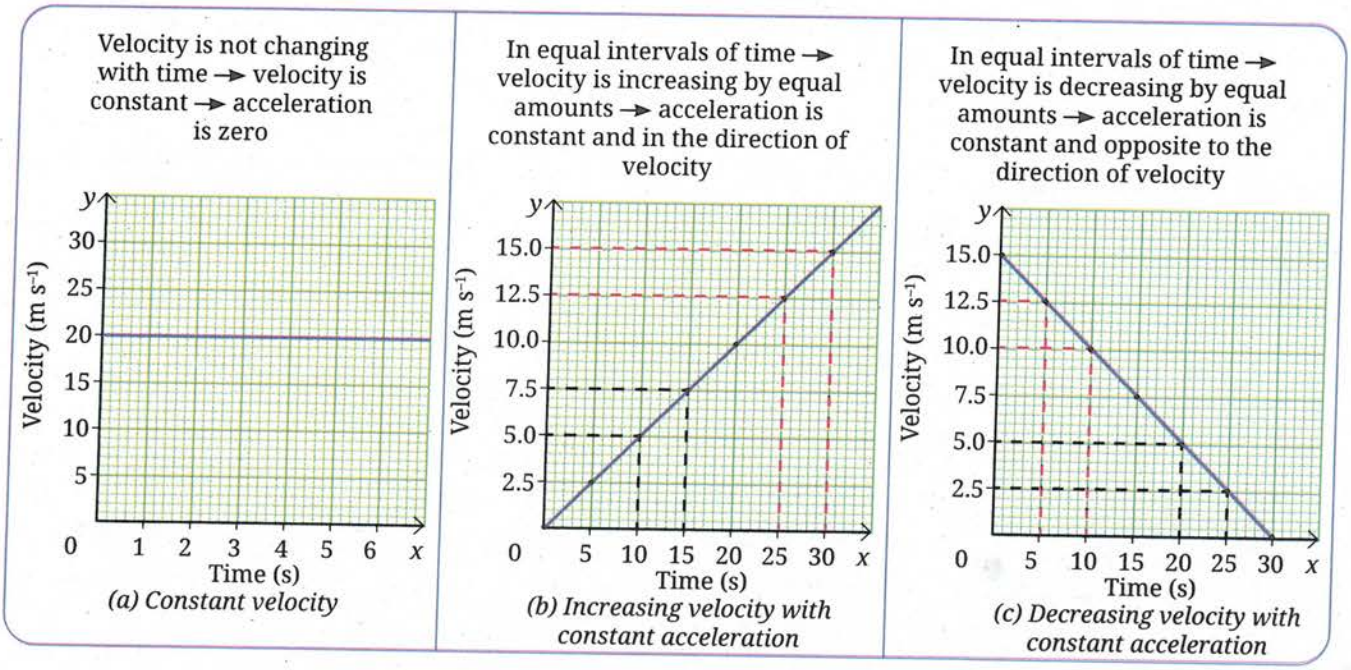


Fig. 4.17: Velocity-time graph of a moving car

When the velocity of the car is constant, the velocity-time graph is a straight line parallel to the x-axis (Fig. 4.17a) and acceleration is zero. A straight line velocity-time graph as shown in Fig. 4.17b indicates that the velocity is increasing with a constant acceleration (in the direction of velocity). Whereas, a straight line velocity-time graph as shown in Fig. 4.17c indicates that the velocity is decreasing with a constant acceleration (opposite to the direction of velocity).

Which physical quantities can be obtained from a velocity-time graph?

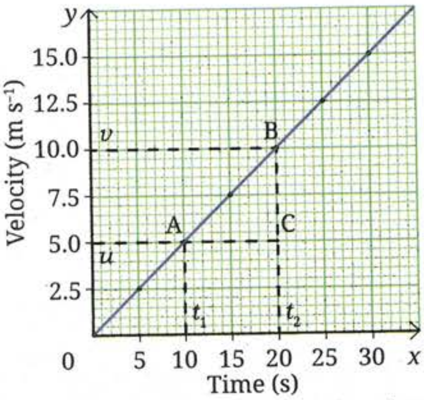


Fig. 4.17(d): Calculating acceleration from a velocity-time graph

Apart from finding the magnitude of velocity of the object at each instant of time, what other physical quantities can be calculated from the velocity-time graph?

Slope of the straight line on graph

In Section 4.2.2, we found that velocity can be determined from the slope of the straight line on position-time graph. What can you find from the slope of the straight line on a velocity-time graph? The slope of the line on velocity-time graph gives how fast the velocity is changing with time, i.e., the acceleration.

For the graph shown in Fig. 4.17a, there is no change in the height of the line from the x-axis, i.e., its slope is zero. Hence, the velocity is constant and the acceleration is zero in this case.

Now consider the graph shown in Fig. 4.17d which is the same as Fig. 4.17b, except for some markings. Consider a part of the line, AB. Suppose at time t_1 corresponding to point A, the velocity is denoted by 'u', and at time t_2 corresponding to point B, it is represented by 'v'. By dividing the change in velocity (BC) by the change in time (CA), you get, $a = \frac{v - u}{t_2 - t_1} = \frac{BC}{CA}$

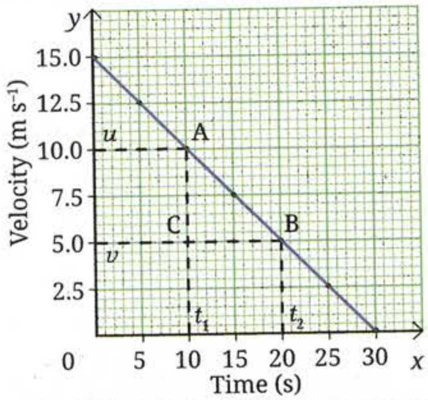


Fig. 4.17(e): Calculating acceleration from a velocity-time graph

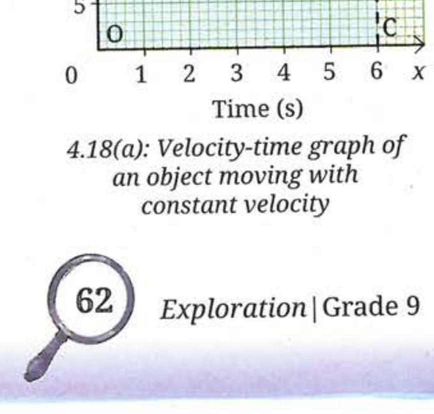
Substituting the values from graph, we obtain the magnitude of average acceleration between the time interval from 10 s to 20 s

$$a = \frac{10 \text{ m s}^{-1} - 5 \text{ m s}^{-1}}{20 \text{ s} - 10 \text{ s}} = \frac{5 \text{ m s}^{-1}}{10 \text{ s}} = 0.5 \text{ m s}^{-2}$$

If we follow the above steps for the graph shown in Fig. 4.17e which is same as Fig. 4.17c, we obtain average acceleration to be -0.5 m s^{-2}. The minus sign indicates that the direction of acceleration is opposite to the direction of velocity (as the velocity is decreasing).

Can you calculate some other physical quantity from the velocity-time graph?

Area enclosed by the line on graph and time axis



4.18(a): Velocity-time graph of an object moving with constant velocity

The graphs shown in Fig. 4.18 are same as Fig. 4.17, except that some parts between the line on graph and the time axis are shaded. Does the area of the shaded part represent some physical quantity?

In Fig. 4.18a, OA is magnitude of the velocity and OC is the time interval.

So, area of rectangle OABC = OA × OC = velocity × time interval (Since, the velocity is constant, it is equal to the average velocity).

Using Eq. (4.2a), we can say,

area of rectangle OABC = displacement

Substituting the values from graph, we obtain

displacement between 0 s and 6 s = area of OABC

= 20 m s^{-1} × 6 s = 120 m

This is the displacement of the car from the origin in 6 seconds. You have found that the area enclosed by the velocity-time graph and the time axis for a desired time interval is equal to the displacement in that time interval.

How can you determine the displacement from the graph given in Fig. 4.18b? Suppose you want to find the displacement between 10 s to 20 s, corresponding to the graph points A and B. We calculate the area between AB and the time axis to obtain the displacement of the object which is moving with a constant acceleration. Thus,

displacement between 10 s to 20 s = area of ABDE

= area of the rectangle ACDE + area of the triangle ABC

$$= (\text{CD} \times \text{DE}) + \left(\frac{1}{2} \times \text{CA} \times \text{BC}\right)$$

Grade 8 Ganita Prakash Part II Chapter 7

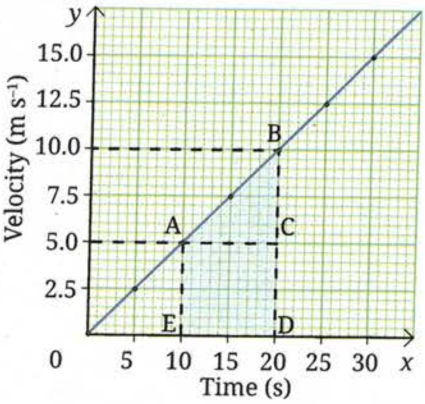


Fig. 4.18(b): Velocity-time graph of an object moving with changing velocity with constant acceleration

Substituting the values, we obtain

$$\text{displacement} = (5\text{ m s}^{-1} \times 10\text{ s}) + \left(\frac{1}{2} \times 10\text{ s} \times 5\text{ m s}^{-1}\right)$$

$$= 50\text{ m} + 25\text{ m} = 75\text{ m}$$

This is the displacement of the car between 10 s and 20 s.

We learnt that by finding the slope and area from velocity-time graph for motion with constant acceleration, we can determine acceleration and displacement, respectively.

You learnt how to represent motion by graphs. Let us now learn about the equations which describe the motion of an object.

4.3 Kinematic Equations for Motion in a Straight Line with Constant Acceleration

Let us consider the special case of motion with constant acceleration and try to derive some equations for analysing such motions. Since the acceleration is constant, acceleration at each instant will be equal to the average acceleration over any time interval.

Using the definition of average acceleration given by Eq. (4.3c),

$$a = \frac{v-u}{t}$$

where u is initial velocity at $t = 0$ s, v is final velocity at time t, time interval is $t - 0 = t$, over which the change in velocity occurs and a is the acceleration, we can write

$$at = v - u$$

$$v = u + at \qquad (4.4a)$$

This equation allows us to calculate velocity (v) at all times if initial velocity (u) and acceleration (a) are known.

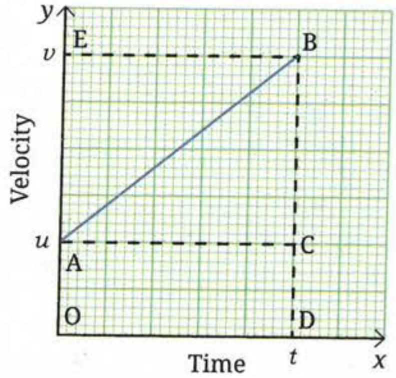


Fig. 4.19: Velocity-time graph where the initial velocity of object is not zero

The velocity-time graph of Eq. (4.4a) is as shown in Fig. 4.19. This is similar to the graph shown in Fig. 4.18 but now the initial velocity of the object is not zero. The initial velocity (represented by AO) is u and the final velocity at time t (represented by EO) is v. The graph is a straight line indicating that the velocity changes with constant acceleration. The slope of the graph gives the acceleration.

As learnt in the earlier section, the displacement s of the object during the time interval t is given by the area enclosed within OABD. Thus,

$$s = \text{area of OABD}$$

$$= \text{area of the rectangle OACD} + \text{area of the triangle ABC}$$

$$= (\text{AO} \times \text{DO}) + \left(\frac{1}{2} \times \text{CA} \times \text{BC}\right)$$

Substituting AO = u, DO = CA = t and BC = BD – CD = EO – AO = $(v - u)$, we obtain

$$s = u \times t + \frac{1}{2} \times \left[t \times (v - u)\right]$$

Substituting the value of $(v - u)$ from Eq. (4.4a),

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

$$s = ut + \frac{1}{2} \times at^2 \qquad (4.4b)$$

These two equations (Eq. 4.4a and Eq. 4.4b) are the primary equations. Combining these equations in different ways, we can obtain three more equations. Let us derive one of those by eliminating t in Eq. (4.4b) (the remaining two equations are given as an exercise in 'The Journey Beyond' at the end of the chapter).

From Eq. (4.4a), we get

$$t = \frac{v - u}{a}$$

Substituting this in Eq. (4.4b), we obtain

$$s = u\left[\frac{v - u}{a}\right] + \frac{1}{2} \times a\left[\frac{v - u}{a}\right]^2$$

$$\Rightarrow \quad s = \frac{uv - u^2}{a} + \frac{u^2 + v^2 - 2uv}{2a}$$

$$\Rightarrow \quad s = \frac{2uv - 2u^2 + u^2 + v^2 - 2uv}{2a}$$

$$\Rightarrow \quad s = \frac{-u^2 + v^2}{2a}$$

$$\Rightarrow \quad 2as = -u^2 + v^2$$

$$\Rightarrow \quad v^2 = u^2 + 2as \qquad (4.4c)$$

For the motion of an object in a straight line with constant acceleration, the five physical quantities-displacement (s), time interval (t), initial velocity (u), final velocity (v) and acceleration (a), can be related by the following set of equations,

$$v = u + at \qquad (4.4a)$$

$$s = ut + \frac{1}{2}at^2 \qquad (4.4b)$$

$$v^2 = u^2 + 2as \qquad (4.4c)$$

These are known as **kinematic equations**. These equations provide a mathematical description of how the motion of an object changes with time.

Using these equations, it is possible to predict position or velocity of the object at a future time.

Note

These kinematic equations are valid only when the acceleration is constant. While using kinematic equations for motion in a straight line in one direction, remember that distance travelled and magnitude of displacement are equal, and speed and magnitude of velocity are also equal. In motion in a straight line in both directions, the sign of u, v, a, and s in these equations tells us about the direction of that particular quantity.

Example 4.8: Suppose a car is moving on a highway and brakes are applied, which cause an acceleration of -4 m s^{-2}. How much will be the distance travelled by the car before coming to a stop, if the car was moving with a velocity of (i) 54 km h^{-1}, and (ii) 108 km h^{-1} when the brakes were applied?

Answer:

Given: $a = -4$ m s^{-2}, $v = 0$ m s^{-1}

Suppose the initial velocity is u and the distance travelled is s.

(i) $u = 54$ km h^{-1} = 15 m s^{-1}

(ii) $u = 108$ km h^{-1} = 30 m s^{-1}

Using Eq. (4.4c)

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

$$(0 \text{ m s}^{-1})^2 = u^2 + 2 \times (-4 \text{ m s}^{-2}) \times s$$

$$0 = u^2 - 8 \times s \qquad \Rightarrow \quad s = \frac{u^2}{8}$$

Substituting the value of u, we obtain (i) 28.1 m, and (ii) 112.5 m.

Bridging Science and Society

When brakes are applied to a moving vehicle, it moves some distance before coming to a stop. The distance travelled depends upon the velocity of the vehicle when the brakes are applied, the road surface (wet, dry, etc.), the braking capacity of the vehicle (the negative acceleration caused by the brakes) as well as the driver's reaction time. Can you now understand why it is important to maintain a safe distance from the vehicle moving ahead of your vehicle (Fig. 4.20) and how this distance needs to be adjusted given your initial velocity?

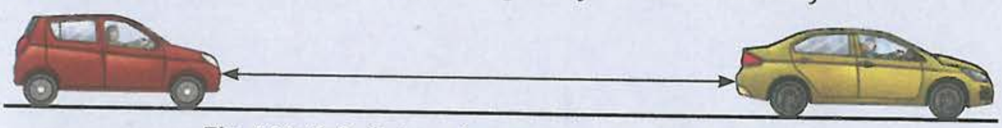


Fig. 4.20: Safe distance between two moving vehicles

There is a vehicle-to-vehicle (V2V) communication technology, now being developed in many countries including India, which allows vehicles to exchange signals and warns drivers of possible collisions.

Till now, in this chapter, we have been discussing about motion in a straight line which is also called motion in one dimension. Let us now explore motion in a plane.

4.4 Motion in a Plane

Motion in a plane, such as a vehicle overtaking another, the path of a kicked ball or a satellite moving in a circular path, is called motion in two dimensions (Fig. 4.21).

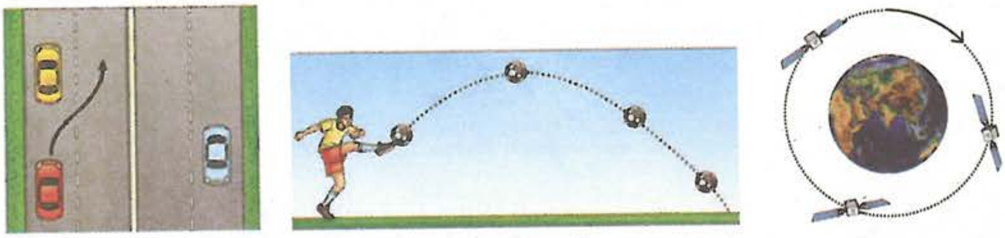


Fig. 4.21: Motion in a plane

4.4.1 Uniform circular motion

Grade 6 Curiosity Chapter 5

Do you remember learning about circular motion in an earlier grade? When an object moves in a circular path, its motion is called circular motion.

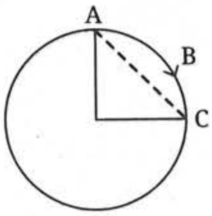


Fig. 4.22: Top view of merry-go-round in circular motion

Suppose a child is sitting on a moving merry-go-around. The child, moving on a circular path, moves from A to B to C as shown in Fig. 4.22. What is the distance travelled by the child? What is their displacement from their original position? The distance travelled by the child is the curve ABC and displacement is the straight-line AC. As you can see both are not equal.

What is the distance travelled by the child in making one revolution (going round the circle once)? It is equal to the circumference of the circle. So, if the radius of the circular path is R, the distance travelled by the child in making one revolution is $2\pi R$. On the other hand, the displacement is zero, since the child comes back to its original position after making one revolution.

If an object takes time T to make one revolution, its average speed v_{av} will be (using Eq. 4.1)

$$v_{av} = \frac{2\pi R}{T} \tag{4.5}$$

while the average velocity during the time interval T will be 0, since the displacement is 0.

Note

We calculated the average speed (Eq. 4.5) for one revolution but for uniform circular motion since the speed is constant, its value is the same at every point on the circle.

Let us now consider a particular case of circular motion where the speed of the object is constant. When an object moves in a circular path with constant (uniform) speed, its motion is called **uniform circular motion**.

In case of uniform circular motion, the speed is constant but what about the direction of velocity at an instant? Is it changing?

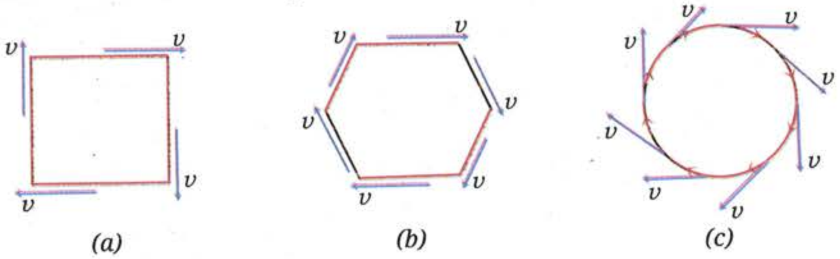


Fig. 4.23: An athlete running along (a) a rectangular track, (b) a hexagonal track, and (c) a circular track

Imagine an athlete running along a closed path. In Fig. 4.23a, the athlete follows a rectangular track (ABCD), running at a uniform speed on the straight sections (AB, BC, CD and DA). The athlete changes direction four times to complete one round. In Fig. 4.23b, the athlete is running along a hexagonal path. In this case, the athlete changes direction six times to complete one round. What happens if we keep increasing the number of sides indefinitely? As the number of sides increases, the athlete has to take turns more and more frequently. Finally, the track approaches a circle, with each side decreasing to a point and the direction of athlete's velocity changes continuously.

Note

In uniform circular motion, the speed is constant at every point on the circle, it is only the direction of velocity that changes.

Activity 4.5: Let us investigate

1. Take a ring, such as an adhesive tape ring and one marble.
2. Place the ring flat on a smooth surface and throw the marble inside the ring in a way that it rotates along the inner boundary of the ring (Fig. 4.24).
3. **Predict** what will happen if you lift the ring while the marble is moving.
4. Now, after one or two complete revolutions of the marble, pick up the ring without disturbing the motion of the marble. What do you observe? Does the marble continue moving in a circular motion? Or does it move in some other manner?
5. Repeat the activity multiple times to confirm the result.

Fig. 4.24: A marble moving inside a ring

When the marble is released by lifting the ring, it moves in a straight line. This happened because once the marble is released, it continues to move in the direction it has been moving at the instant the ring was removed. You will learn the reason for this in a later chapter.

Note

In everyday life, we say that a vehicle is accelerating when the magnitude of its velocity is changing but we often fail to recognise that there can be acceleration when there is only a change in the direction of velocity.

Ready to Go Beyond

The velocity at a point is along the tangent to the circle at that point, in the direction of motion. A straight line that meets the circle at one and only point is called a tangent to the circle at that point (Fig. 4.25). You will learn more about it in Mathematics.

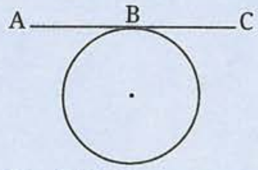


Fig. 4.25: Tangent to a circle at point B

You know that acceleration is non-zero if the velocity of an object changes. The velocity changes if either its magnitude or direction, or both changes. In uniform circular motion, the motion of the object is accelerated because the direction of its velocity continuously changes.

Ready to Go Beyond

Motion in space, such as a car climbing up a mountain road (Fig. 4.26), bird flying in the sky or an aircraft moving through air, is called motion in three dimensions. You will learn about it in higher grades. Next Level Up

Fig. 4.26: A mountain road

In real world, the conditions for uniform circular motion — constant speed and a circular path — are often not met. So, uniform circular motion is an idealised model of the real-world situations. Still, it is a useful model as it serves as the foundation for more complex real-world situations, such as motion of planets revolving around the Sun or a vehicle making a circular turn.

At a Glance

- The distance and direction of an object with respect to the reference point, at any instant of time, describes the position of the object at that instant of time.
- If the position of the object with respect to a reference point changes with time, the object is said to be in motion.
- Displacement is the net change in the position of the object between two given instants of time.
- The average speed of an object is the total distance travelled divided by the time interval during which this distance is covered.
- The average velocity of an object in a time interval is the change in position (also known as displacement) divided by the time interval in which the change in position (or displacement) occurs.
- The average acceleration of an object over a time interval is the change in its velocity divided by the time interval.
- For the motion of an object in a straight line with constant acceleration, the five physical quantities — displacement (s), time interval (t), initial velocity (u), final velocity (v) and acceleration (a), can be related by the following set of kinematic equations,

$$v = u + at \qquad s = ut + \frac{1}{2}at^2 \qquad v^2 = u^2 + 2as$$

- When an object moves in a circular path with constant (uniform) speed, its motion is called the uniform circular motion.

Revise, Reflect, Refine

1. My father went to a shop from home which is located at a distance of 250 m on a straight road. On reaching there, he discovered that he forgot to carry a cloth bag. He came home to take it, went to the shop again, bought provisions and came back home. How much was the total distance travelled by him? What was his displacement from home?
2. A student runs from the ground floor to the fourth floor of a school building to collect a book and then comes down to their classroom on the second floor. If the height of each floor is 3 m, find:
   (i) the total vertical distance travelled, and
   (ii) their displacement from the starting point.

3. A girl is riding her scooter and finds that its speedometer reading is constant. Is it possible for her scooter to be accelerating and if so, how?
4. 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.
5. A motorbike moving with initial velocity 28 m s^{-1} and constant acceleration stops after travelling 98 m. Find the acceleration of the motorbike and the time taken to come to a stop.
6. Fig. 4.27 shows a position-time graph of two objects A and B that are moving along the parallel tracks in the same direction. Do objects A and B ever have equal velocity? Justify your answer.

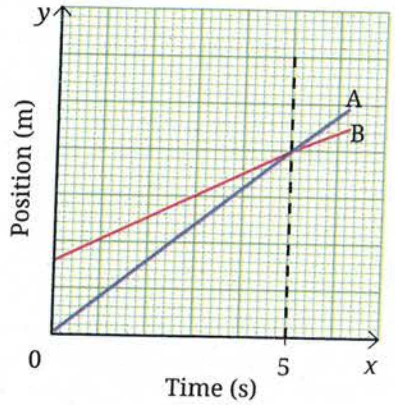


Fig. 4.27

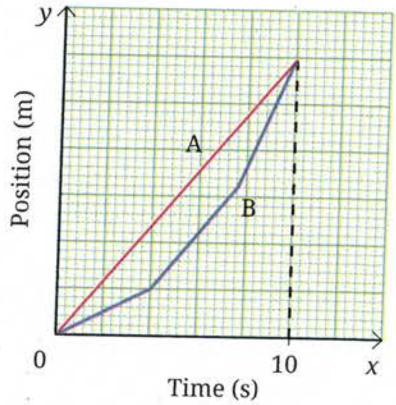


Fig. 4.28

7. A graph in Fig. 4.28 shows the change in position with time for two objects A and B moving in a straight line from 0 to 10 seconds. Choose the correct option(s).
   (i) The average velocity of both over the 10 s time interval is equal since they have the same initial and final positions.
   (ii) The average speeds of both over the 10 s time interval are equal since both cover equal distance in equal time.
   (iii) The average speed of A over the 10 s time interval is lower than that of B since it covers a shorter distance than B in 10 seconds.
   (iv) The average speed of A over the 10 s time interval is greater than that of B since B's speed is lower than A's in some segments.
8. A truck driver driving at the speed of 54 km h^{-1} notices a road sign with a speed limit of 40 km h^{-1} (Fig. 4.29) for trucks. He slows down to 36 km h^{-1} in 36 s. What was the distance travelled by him during this time? Assume the acceleration to be constant while slowing down.

Fig. 4.29

9. A car starts from rest and accelerates uniformly to 20 m s^{-1} in 5 seconds. It then travels at 20 m s^{-1} for 10 seconds and finally applies the brake (with uniform acceleration) to stop in 6 seconds. Find the total distance travelled.
10. A bus is travelling at 36 km h^{-1} when the driver sees an obstacle 30 m ahead. The driver takes 0.5 seconds to react before pressing the brake. Once the brake is applied, the velocity of the bus reduces with constant acceleration of 2.5 m s^{-2}. Will the bus be able to stop before reaching the obstacle?

11. A student said, "The Earth moves around the Sun". In this context, discuss whether an object kept on the Earth can be considered to be at rest.

12. The velocity-time graph from 0 s to 120 s for a cyclist is shown in Fig. 4.30. Shade the areas (in different colours) representing the displacement of the cyclist
    (i) while cyclist is moving with constant velocity.
    (ii) when the velocity of cyclist is decreasing.
    Also, calculate the displacement and average acceleration in the 120 s time interval.

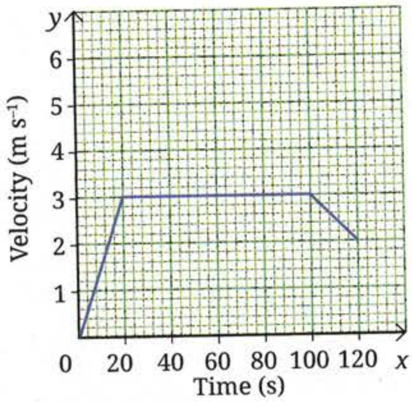


Fig. 4.30

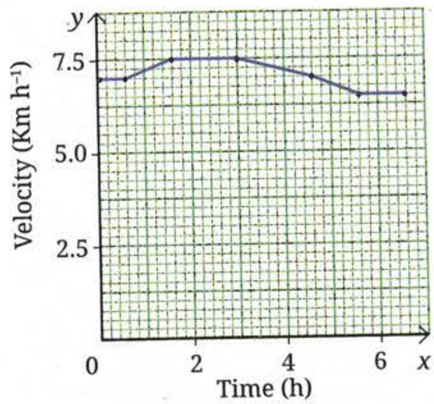


Fig. 4.31

13. A girl is preparing for her first marathon by running on a straight road. She uses a smartwatch to calculate her running speed at different intervals. The graph (Fig. 4.31) depicts her velocity versus time. Estimate the running distance based on the graph.

14. On entering a state highway, a car continues to move with a constant velocity of 6 m s^{-1} for 2 minutes and then accelerates with a constant acceleration 1 m s^{-2} for 6 seconds. Find the displacement of the car on the state highway in the 2 min 6 s time interval by drawing a velocity-time graph for its motion.

15. Two cars A and B start moving with a constant acceleration from rest in a straight line. Car A attains a velocity of 5 m s^{-1} in 5 s. Car B attains a velocity of 3 m s^{-1} in 10 s. Plot the velocity-time graphs for both the cars in the same graph. Using the graph, calculate the displacement mentioned in the two time intervals (Hint: Calculate the acceleration in both cases. Then calculate their velocities at five instants of time to plot the graph).

16. Rohan studies science from 6 PM to 7:30 PM at home. Consider the tip of the minute's hand of the wall clock. During the given time interval, what is its:
    (i) distance travelled,
    (ii) displacement,
    (iii) speed, and
    (iv) velocity.
    The length of the minute's hand is 7 cm (Fig. 4.32).

Fig. 4.32

The Journey Beyond

- Take a cardboard disc (radius ~ 8 cm) (Fig. 4.33). Write numbers 1 to 12 on the outer part (7 cm from the centre) and the letters 'ABCDEF' on the inner part (4 cm from the centre), using the same font size. Spin the disc slowly, then faster and observe how the numbers and letters appear. Why do the numbers fade or disappear while the letters remain visible? Are the speeds of the numbers and letters the same or different? Justify your answer.

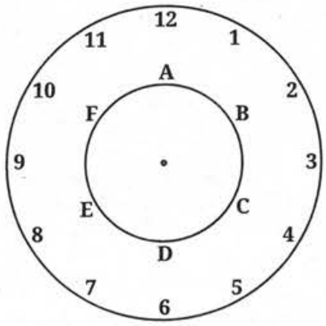


Fig. 4.33

- Many smartphones have an inbuilt accelerometer that can detect very small accelerations. Install an app, such as Phyphox (phyphox.org) and open 'Accelerometer' (without *g*). Note the readings when (i) the phone is on an outstretched palm, and (ii) the phone is kept on the floor. What differences do you observe? What does this tell you about motion and acceleration in real situations? (Such tiny, involuntary movements are also studied in medical research, for example, in movement disorders) This activity is recommended to be performed as a classroom group activity facilitated by teacher.
- For motion in a straight line with constant acceleration, we derived two primary equations given by Eq. (4.4a) and (4.4b). Using these two equations, three more equations can be derived, out of which we derived one given in Eq. (4.4c). Derive the remaining two equations given below

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

Grade 8 Ganita Prakash Part II Chapter 7

  In mathematics, you have learnt the formula for calculating the area of a trapezium. Using that formula, derive the second equation given above.
- Plot graphs for data given in Table 4.4, using different X and Y scales, on different graph papers. Comapre the graphs to find how the appearance of graph is affected by the choice of scales and decide which scale is better and why. Now repeat this with any graph plotting app. Such apps generally automatically adjust the axes to fit the data well on the screen.
- Talk to a motor mechanic about how a vehicle's braking or stopping distance is affected by: (i) wet roads, (ii) worn-out tyres, (iii) higher vehicle mass, (iv) driving at night, (v) fog, (vi) severe weather (rain, snow, storm), and (vii) driver reaction time. Using this information, design safety posters for your school and prepare a short skit to present it in the assembly.

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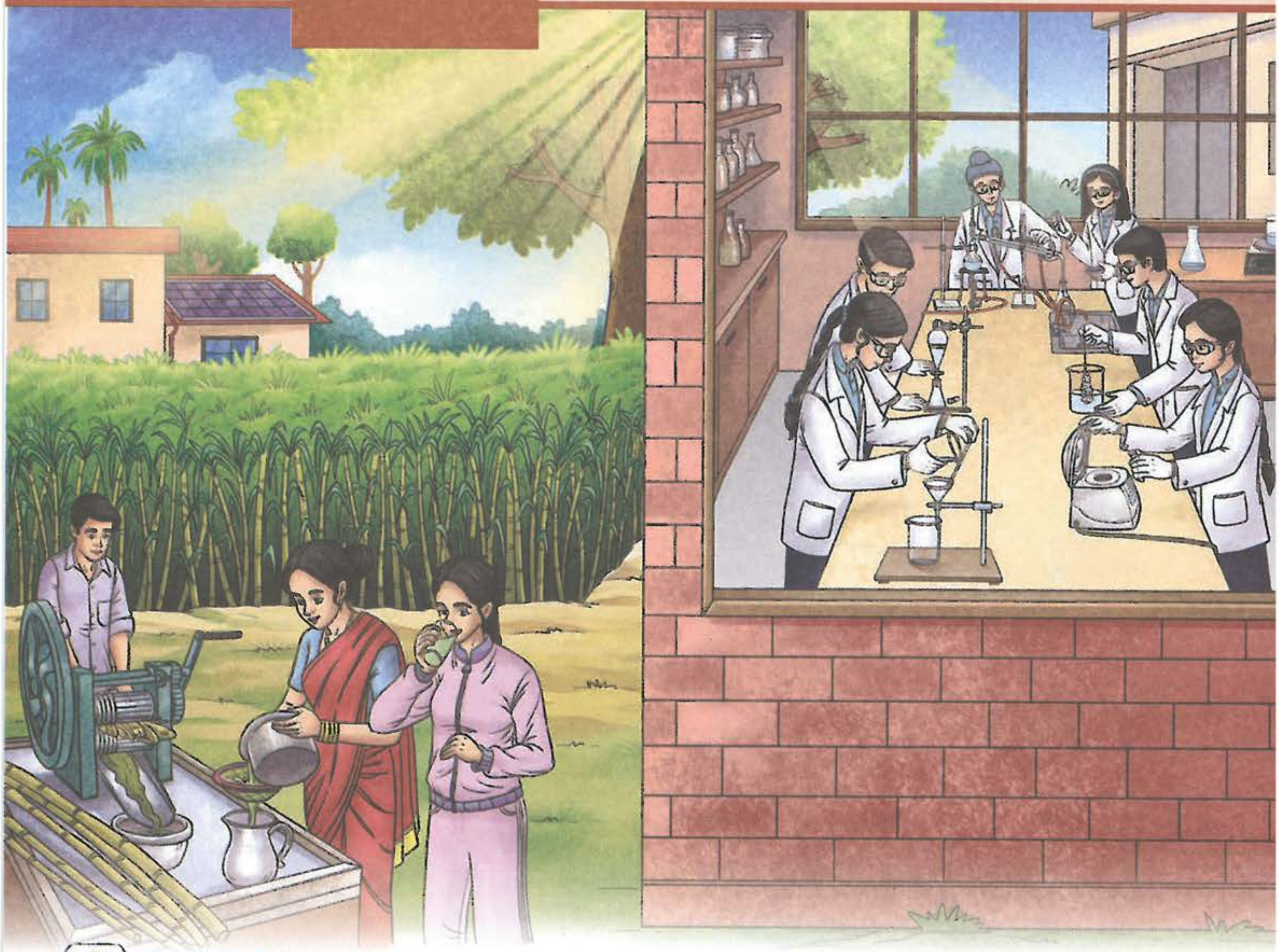
Chapter 5

Exploring Mixtures and their Separation



Think It Over

- Why do suspended particles settle in muddy water over time but not in milk?
- How is evaporation different from boiling?
- Why do you see bright rays of sunlight when it passes through small gaps between the leaves of a dense tree?

Have you ever wondered how sweet, white crystals of sugar are obtained from tall, green sugarcane plants? Or how do doctors detect diseases like malaria using just a few drops of blood? Many such everyday activities are made possible by techniques based on the fascinating science of separating mixtures.

Grade 6 *Curiosity* Chapter 9

You have learnt about mixtures and some simple methods to separate them. In this chapter, you will **explore** mixtures in greater depth, including their properties, behaviour and the various techniques used to separate them. From industrial processes like sugar production to life-saving medical tests, the separation of mixtures plays a crucial role in our daily lives.

5.1 How Can We Classify Mixtures?

Grade 8 Curiosity Chapter 9

You have learnt that a mixture of sugar and water has a uniform composition throughout. A well-stirred mixture of sugar and water is equally sweet in the first and the last sip. Such a mixture is called a **homogeneous mixture** (Fig. 5.1) or a **solution**. Other examples of homogeneous mixtures are vinegar (acetic acid in water), aerated drinks like soda (carbon dioxide in water), etc. A solution always remains homogeneous.

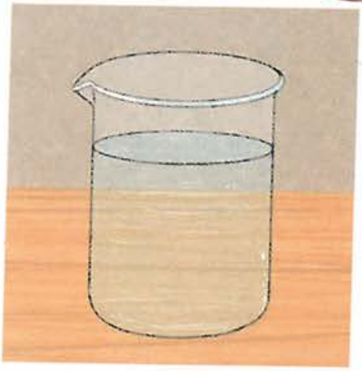


Fig. 5.1: Homogeneous mixture

On the other hand, a stirred mixture of sand and water is not uniform. The sand particles are easily visible in the water and settle with time. Such a mixture is called a **heterogeneous mixture** (Fig. 5.2). Is the mixture of oil and water homogeneous or heterogeneous? Can you think of some other heterogeneous mixtures?

Fig. 5.2: Heterogeneous mixture

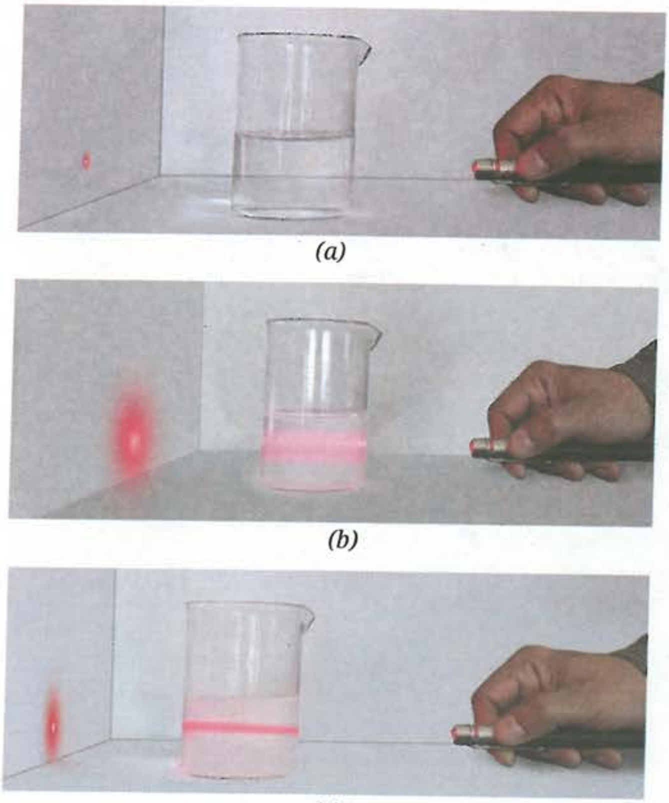
Activity 5.1: Let us experiment — Group activity

Divide the class into three groups — A, B and C. Each group prepares a mixture in a colourless, transparent glass tumbler or a 100 mL beaker by following these steps:

1. Group A: Add one spatula of common salt to 50 mL of water in a beaker and stir it well. Label it A.
2. Group B: Add one spatula of chalk powder to 50 mL of water in a beaker and stir it well. Label it B.
3. Group C: Add a few drops of milk to 50 mL of water in a beaker and stir it well. Label it C.
4. Are the particles visible in each mixture? **Record** your observations.
5. Direct the light from a laser pointer through the beakers containing the mixtures (Fig. 5.3) and **observe** it from the side of the beaker in a direction perpendicular to the laser beam. Record your observations.

Safety first: Do not look directly into the laser beam. It can cause irreversible eye damage.

6. **Predict** what you would observe in each of the beakers if you leave them undisturbed for a few minutes.



(a) (b) (c)

Fig. 5.3: Passing laser light through various mixtures (a) salt and water, (b) chalk powder and water, and (c) milk and water

7. Set up a filtration apparatus and filter each mixture separately. Is there any residue left on the filter paper?
8. Based on your observations, do you think these are the same types of mixtures or are they different?

These are indeed different types of mixtures. How? Let us explore further!

5.2 Solutions

Grade 8 Curiosity Chapter 9

You have learnt that solutions are homogeneous mixtures. You have also learnt that solutions are prepared when a **solute** (the substance that gets dissolved) is mixed with a **solvent** (the substance that dissolves the solute). In the mixture of sugar and water, sugar is the solute, and water is the solvent. In what proportion are a solute and a solvent present in a solution? Can these be expressed quantitatively?

5.2.1 Concentration of a solution

Grade 6 Curiosity Chapter 6

You have learnt how Oral Rehydration Solution (ORS) is prepared. We add specified amounts of salt and sugar to a fixed amount of water to prepare ORS. If we change the amount of salt or sugar added to the same volume of water, or change the volume of water for the specified amounts of salt and sugar, we will get a solution of salt and sugar in water but that will not be ORS. In other words, we cannot freely add any amount of salt and sugar to a fixed amount of water to make ORS.

Note

Not all sugary drinks prepared at home or sold in the market are ORS.

Let us take another example. When farmers spray pesticides on their crops, they must mix the right amount of pesticide with a fixed amount of water to prepare a solution. If they do not do so, what is likely to happen? Too little pesticide may not protect crops, while too much can damage crops, soil and the environment.

Meet a Scientist

Dilip Mahalanabis, an Indian paediatrician, first developed and implemented the treatment for dehydration caused by diseases, such as diarrhoea and cholera. He formulated the ORS that has revolutionised rehydration therapy. It has saved millions of lives after the World Health Organization (WHO) popularised it worldwide.

Can you think of other such examples?

The right proportion is always essential when preparing a solution.

The amount of solute dissolved in a given amount of solvent or solution is termed as the **concentration** of the solution.

Understanding concentration is essential not only in science laboratories but also in everyday life, whether in medicine, agriculture, food, cosmetics, or even while making a simple cup of tea!

5.2.2 How do we express concentration?

Let us now explore the different ways to express the concentration of a solution, and understand where and why each method is more suitable.

Collect some commercial packaged products (Fig. 5.4) and note down the information given for each item.

Next Level Up

The concentration of a solution can be expressed in several ways, a common one being the percentage which we are discussing here. You will learn about other methods in higher grades.

The three main ways to express the concentration of a solution in terms of percentage are given below.

A. Mass by mass percentage (% *m/m* or % *w/w*)

This method is commonly used to express the concentration of homogeneous mixtures. It tells us how many grams of solute are present in 100 grams of the total solution.

This can be expressed mathematically as,

$$\text{Mass by mass percentage} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100 \qquad (5.1)$$

This method of expressing concentration is also used for heterogeneous mixtures, such as milk powder (Fig. 5.4a) and spice mixtures. It is also used to label the composition of packaged foods, showing how much salt, sugar, or protein is present in them.

Example 5.1: If 10 g of salt is dissolved in 90 g of water, calculate the mass by mass percentage of the solution formed.

Answer: Mass of salt (solute) = 10 g

Mass of water (solvent) = 90 g

Total mass of solution = Mass of solute + Mass of solvent

= 10 g + 90 g = 100 g

$$\text{Mass by mass percentage} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$$

$$= \frac{10\text{ g}}{100\text{ g}} \times 100 = 10\ \%\ m/m$$

B. Mass by volume percentage (% *m/v* or % *w/v*)

This method is used where measuring the volume of a liquid is easier than weighing it, for example, in medicines and laboratories. A common example is 5% glucose solution (Fig. 5.4b). It tells us how many grams of the solute is present in 100 millilitres of the solution.

Mathematically,

$$\text{Mass by volume percentage} = \frac{\text{Mass of solute}}{\text{Volume of solution}} \times 100 \qquad (5.2)$$

Example 5.2: If 5 g of glucose is dissolved in water to make 100 mL of solution, calculate its concentration in mass by volume percentage.

Answer: Mass of glucose (solute) = 5 g

Volume of solution = 100 mL

$$\text{Mass by volume percentage} = \frac{\text{Mass of solute}}{\text{Volume of solution}} \times 100$$

$$= \frac{5\text{ g}}{100\text{ mL}} \times 100 = 5\ \%\ m/v$$

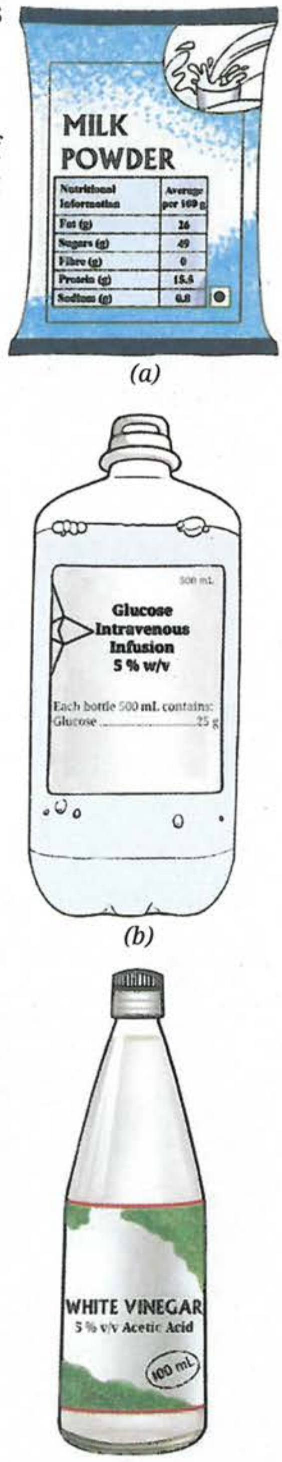


Fig. 5.4: Composition of some commercial packaged products (a) milk powder, (b) glucose solution, and (c) vinegar

Threads of Curiosity

A saline drip in hospitals is usually 0.9 % *m/v* sodium chloride (common salt) in water. That means 0.9 g of salt in 100 mL of solution (Fig. 5.5). 0.9% saline solution is safe for blood and replaces lost fluids in the body.

Fig. 5.5: Saline solution

C. Volume by volume percentage (% *v/v*)

This method is used when two miscible liquids are mixed, for example, in perfumes, cosmetics and vinegar (Fig. 5.4c). The volume by volume percentage (% *v/v*) tells us how many millilitres of the solute is present in 100 millilitres of the solution. Mathematically,

$$\text{Volume by volume percentage} = \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100 \quad (5.3)$$

Example 5.3: If 1 mL of a liquid pesticide is mixed with a sufficient amount of water to form 100 mL of a pesticide spray for rice crop, calculate its volume by volume percentage.

Answer: Volume of pesticide (solute) = 1 mL

Total volume of solution = 100 mL

Volume by volume percentage

$$= \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100$$

$$= \frac{1\text{ mL}}{100\text{ mL}} \times 100 = 1\%\ v/v$$

Note

Commonly used unit in industries is weight by weight percentage (% *w/w*), as weight and mass are generally used interchangeably. Numerically, both % *m/m* and % *w/w* are equal to each other.

Pause and Ponder

1. A common talcum powder contains 4 % *m/m* zinc oxide, which acts as an antiseptic. How much zinc oxide is present in 300 g of the talcum powder?
2. Your mother gives you a bottle of orange juice concentrate to mix with water and serve it to your visiting friends. She asks you to mix two tablespoons of the concentrate with water in a glass tumbler. If each tablespoon measures 15 mL and you make 150 mL of juice per person, what is the % *v/v* of orange juice concentrate in the mixture you prepared?
3. Vinegar, used as a food preservative and additive, contains 5 % *v/v* acetic acid. Glacial acetic acid is a liquid, i.e., 100% acetic acid. If you want to make vinegar from glacial acetic acid, how would you proceed?

5.2.3 Solubility of substances

Grade 8 Curiosity Chapter 9

You have learnt that the maximum amount of solute that dissolves in a fixed quantity of the solvent (100 mL or 100 g) is called its **solubility** at a given temperature. A solution that cannot dissolve any more solute at that temperature is called a **saturated** solution. Why do we mention the temperature? This is because the solubility of a solid solute in a liquid solvent generally increases with temperature. On the other hand, in the case of gases dissolved in liquids, their solubility generally decreases with an increase in temperature. Solubility is an important property used to separate substances from mixtures. Let us explore it further!

Activity 5.2: Let us represent solubility graphically

Consider water as the solvent, and compounds 'A' and 'B' as the solutes. Each substance has a different solubility. A graph of solubility versus temperature is called a **solubility curve**. The solubility curves for 'A' and 'B' as solutes are shown in Fig. 5.6. The x-axis shows temperature (°C), whereas the y-axis indicates the solubility of the solute in grams per 100 g of water.

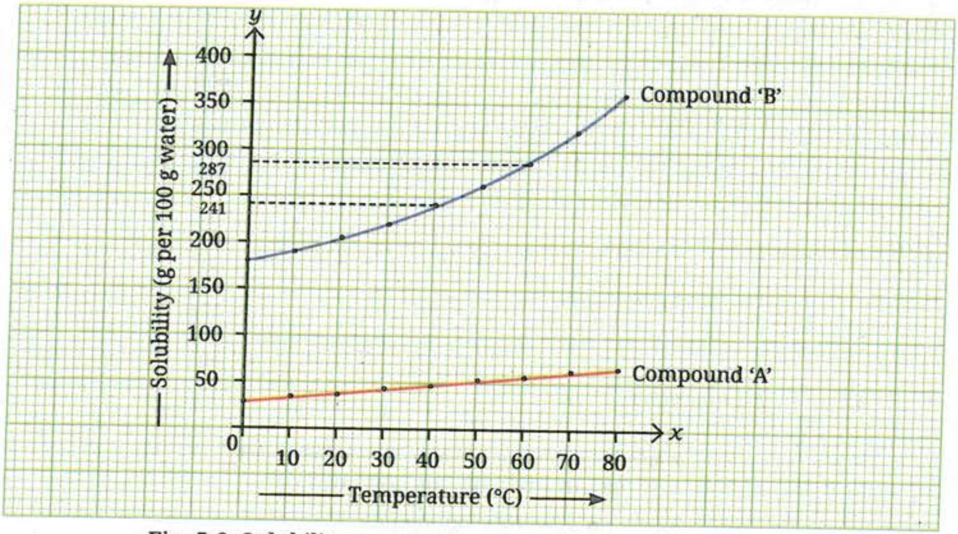


Fig. 5.6: Solubility curves of compounds 'A' and 'B' in water

Based on the information from the above graph, predict which of the two compounds, 'A' or 'B', will dissolve more in a given amount of water at a given temperature?

Observe Fig. 5.6 and fill in the blanks of the following statements:

(i) The solubility of compound 'A' in water at 20 °C is ____________ (less than/more than/similar to) its solubility at 60 °C.

(ii) The solubility of compound 'B' at 20 °C is __________ (less than/more than/similar to) its solubility at 60 °C.

(iii) The solubility of ____________ increases more than that of ____________ with an increase in the temperature.

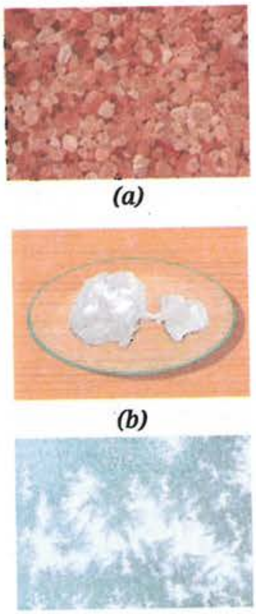
What do you think will happen if you make a saturated solution at a higher temperature and cool it slowly? Let us find out!

5.3 Methods of Separation of Homogeneous Mixtures

5.3.1 Crystallization

You have learnt to prepare a saturated solution. If you take a saturated solution of compound 'B' in water at 60 °C, prepared by dissolving 287 g of compound 'B' in 100 g of water, what will happen if you gradually cool it to 40 °C? As per Fig. 5.6, the solubility of compound 'B' is 241 g per 100 g of water at 40 °C. It implies that only 241 g of compound 'B' can remain in the solution and the rest of it will separate out as a pure solid, often as crystals. A **crystal** is a solid that is made up of particles arranged in a regular geometric pattern.

Grade 8 Curiosity Chapter 9



(a)

(b)

(c)

Fig. 5.7: Crystals of (a) rock salt, (b) candy sugar, and (c) frost

You might have observed many types of crystals in everyday life, such as rock salt crystals (Fig. 5.7a) or sugar crystals (Fig. 5.7b) that grow while making candy sugar (called *mishri* in Hindi). Snowflakes are also crystals formed when water vapour freezes in the air. Even frost on windows is formed when water vapour turns into ice crystals (Fig. 5.7c). This is how crystals form naturally.

In laboratories, the process of forming crystals from a saturated solution is called **crystallization**. This method can be used for the separation of two solids in which one of the compounds is present in small quantity and both are soluble in the same solvent. This method can also be used for purification of solids. The principle of purification by crystallization is based on the differences in the solubility of a substance at different temperatures.

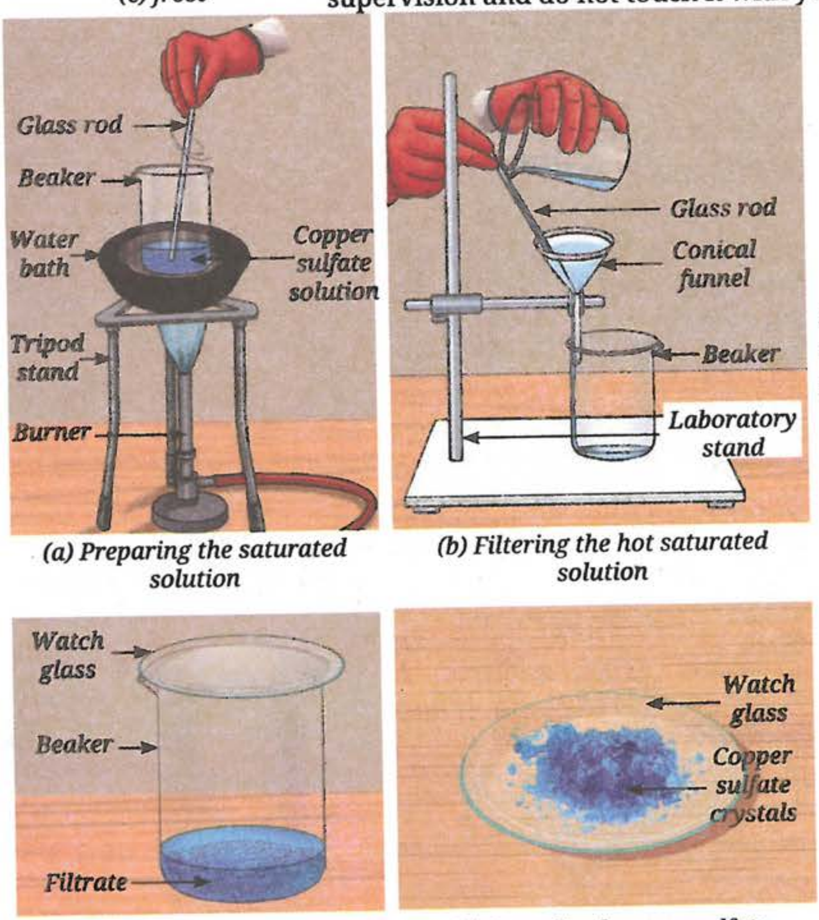
Try creating your own crystals.

> **Note**
> Sulfuric acid is required for the crystallization of only some salts.

Activity 5.3: Let us prepare

1. Collect a sample of copper sulfate (blue vitriol). If copper sulfate is unavailable, you can use common salt as an alternative.

Safety first: Copper sulfate is toxic. Perform the experiment under adult supervision and do not touch it with your bare hands.



(a) Preparing the saturated solution *(b) Filtering the hot saturated solution*

(c) Cooling down the filtrate *(d) Crystals of copper sulfate*

Fig. 5.8: Steps involved in the process of crystallization

2. Take 1 g of copper sulfate and place it in a 100 mL beaker. Add 25 mL of water to the beaker and add a drop of dilute sulfuric acid. Gently heat the mixture in a water bath while stirring constantly. Sulfuric acid helps in making pure crystals by preventing unwanted reactions.

Safety first: It is advised that the teacher should add a drop of sulfuric acid. Handle sulfuric acid very carefully!

3. Gradually, add more copper sulfate until the solution becomes saturated (Fig. 5.8a).
4. Filter the hot solution to remove insoluble impurities (Fig. 5.8b). Collect it in a clean beaker and cover it with a watch glass.
5. Allow the solution to cool slowly without disturbing it (Fig. 5.8c). It gives enough time to the particles in the solution to come together, resulting in the formation of larger, shiny, well-shaped and blue-coloured crystals.
6. Filter the crystals, rinse them with cold water and allow them to dry on a watch glass (Fig. 5.8d).

You may also try:

1. Place 1 – 2 mL of the saturated copper sulfate solution on a small glass plate or a lamination sheet.
2. Leave it for some time. What do you observe?

   Did you get crystals? If yes, is this a good way to experiment? Explain.

Crystallization is a common technique for separating pure substances (crystals) from homogeneous mixtures. When new compounds are prepared, they are often accompanied by unwanted impurities. Crystallization helps to separate the desired pure substance from the undesired impurities.

Think as a Scientist

If a hot, saturated solution of copper sulfate is cooled rapidly in ice-cold water, smaller and less well-formed crystals will form than if it is cooled slowly at room temperature. How would you design and perform an experiment to test this **hypothesis**?

Hint: Prepare a hot saturated solution of copper sulfate and divide it into two equal parts.

Pause and Ponder

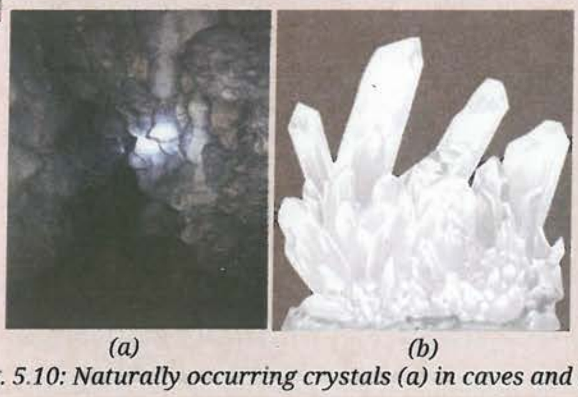
4. Refer to the solubility curves given in Activity 5.2. If equal masses of hot, saturated solutions of compounds 'A' and 'B' are cooled from 80 °C to 60 °C, which solution is likely to deposit more solid?
5. Will there be any change in the size of common salt crystals if the rate of evaporation is increased or decreased? Explain.

Activity 5.4: Let us describe a process

Observe Fig. 5.9, it shows how salt crystals are obtained from seawater. Can you describe the process in your own words?

Fig. 5.9: Steps followed in the salt manufacturing process

Ready to Go Beyond



Have you visited a place where large crystal deposits can be observed in nature? Such crystals can be found in various locations, including mines, caves and even within the Earth's crust. One such example is the Mawsmai Cave (Fig. 5.10a) in Sohra (Cherrapunji), known for its fascinating natural formations. Quartz (Fig. 5.10b) is also one of the beautiful crystals found in nature.

Fig. 5.10: Naturally occurring crystals (a) in caves and (b) quartz

India's Scientific Contributions

Crystallization of salt was an ancient process used by the local communities of the coastal areas in India. The *panga* salt was obtained by boiling concentrated sea brines, while the evaporation of sea water produced the *karkatch* salt. Salt crystals of different sizes were produced by these methods.

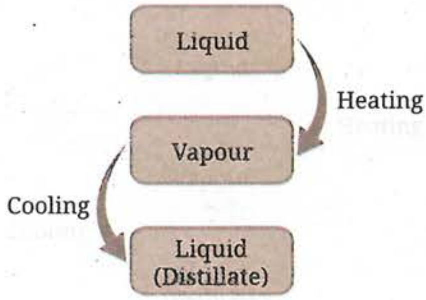


Fig. 5.11: Distillation process

When we allow a solvent to evaporate to get a solute, such as salt from a salt solution, the solvent disappears. However, we may also want to recover the solvent. What should we do then?

While experimenting in the laboratory, a student accidentally mixed acetone and water, two miscible liquids. How can we separate the two miscible liquids? Is it possible to separate the mixture of two miscible liquids by evaporation and obtain both the liquids?

5.3.2 Distillation

A homogeneous mixture of two miscible liquids can be separated by heating the mixture until the liquid with the lower boiling point vaporises. The vapour is then cooled, turning back into liquid (Fig. 5.11). This process is known as **distillation**. It allows the recovery of the solvent or the separation of liquids that differ in boiling point by at least about 25 °C. This method can also be used to separate a liquid from a solution containing dissolved solids.

During the process, vapours of the lower-boiling liquid are passed through a condenser where they are cooled, usually by circulating water or air and condensed as a pure liquid. The pure liquid is collected in a separate vessel, while the solid or other liquid from the mixture remains in the distillation flask. A distillation set-up is shown in Fig. 5.12.

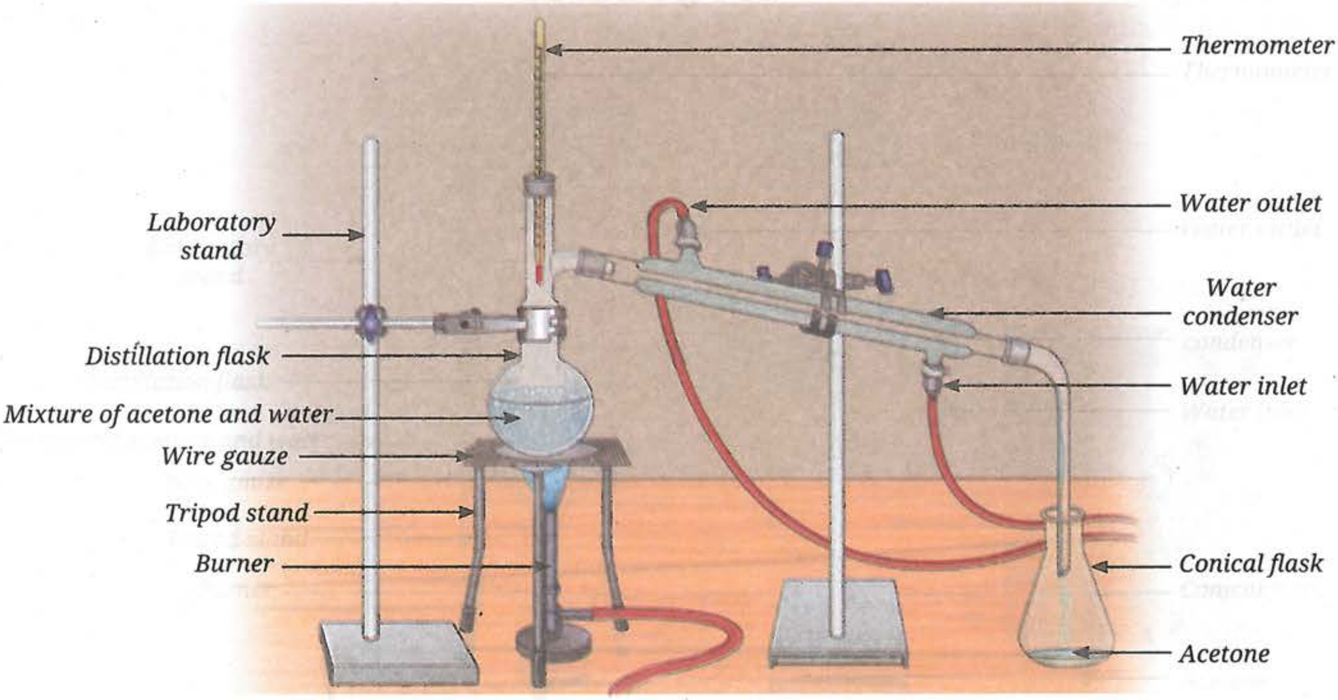


Fig. 5.12: Distillation set-up

A mixture of acetone and water can be separated by distillation because their boiling points differ sufficiently. Acetone boils at about 56 °C and water boils at 100 °C. A large difference in boiling points allows one liquid to vaporise before the vapours of the other liquid are formed in significant amount.

India's Scientific Contributions

The process of distillation has been used for a long time for various purposes, including extraction of fragrances from flowers to make perfumes.

You must have noticed the pleasant earthy smell that rises from the ground after the first rain. In Kannauj, a town in Uttar Pradesh known as the perfume capital of India, this beautiful fragrance is captured and turned into a natural perfume called *Mitti ka Ittar* (earthy fragrance). This perfume is made using a traditional distillation method known as the *Deg-Bhapka* method (Fig. 5.13), which has been passed down through generations in Kannauj. It is in great demand, both in India and around the world. The Fragrance and Flavour Development Centre in Kannauj has facilities for separating flavour and fragrance components from flowers, leaves and other parts of plants. It also supports farmers in cultivating fragrance-producing plants and offers expertise to those looking to establish their own perfume businesses.

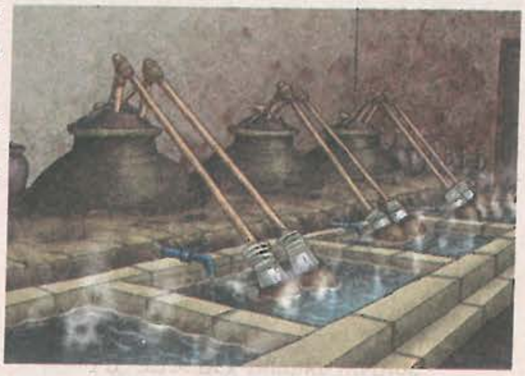
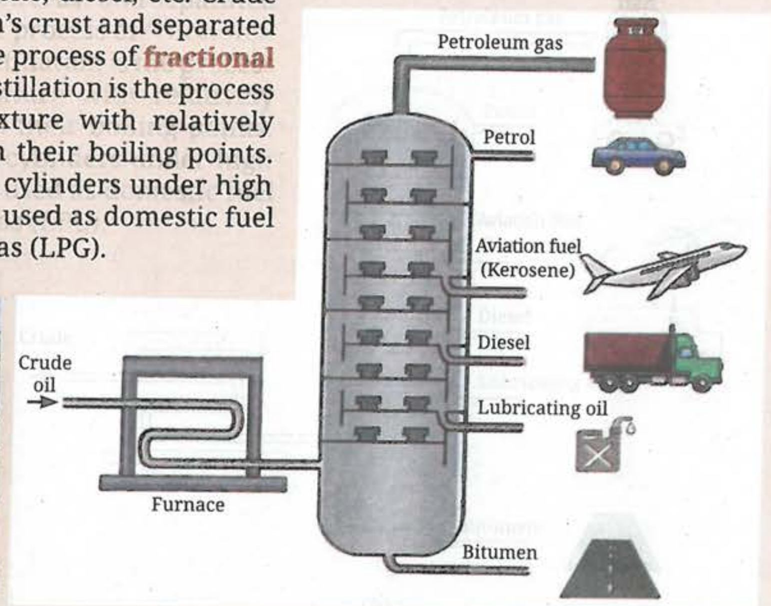


Fig. 5.13: Deg-Bhapka method

Ready to Go Beyond

A petroleum refinery (Fig. 5.14a) is an industrial unit where crude oil is processed to obtain various useful petroleum products. Petroleum products are mixtures of useful gases and liquids, such as petroleum gas, petrol, kerosene, diesel, etc. Crude petroleum is extracted from the Earth's crust and separated into these different fractions using the process of **fractional distillation** (Fig. 5.14b). Fractional distillation is the process of separating components of a mixture with relatively small differences (less then 25 °C) in their boiling points. The gaseous fraction is filled in steel cylinders under high pressure, where it gets liquefied. It is used as domestic fuel in the form of Liquefied Petroleum Gas (LPG).

(a)



(b)

Fig. 5.14: (a) Petroleum refinery, and (b) products of fractional distillation of crude petroleum

Threads of Curiosity

The word 'chromatography' comes from the Greek words *chroma*, meaning 'colour' and *graphein*, meaning 'to write'. It actually means 'writing with colour' because it was first used to separate coloured substances like dyes and inks.

5.3.3 Paper Chromatography

Have you ever observed what happens when a drop of water falls on something written with a sketch pen on a paper? You may have noticed that the colour spreads. If the sketch pen is black, different colours might spread out. If you have not noticed this before, try it now!

Activity 5.5: Let us investigate

1. Take a 3 cm wide strip of chromatographic paper and draw a straight, horizontal line, 2 cm from the bottom of the paper with a pencil (Fig. 5.15a). Alternatively, you can use a strip of filter paper.
2. Mark a spot with a black sketch pen at the centre of the line (Fig. 5.15b).

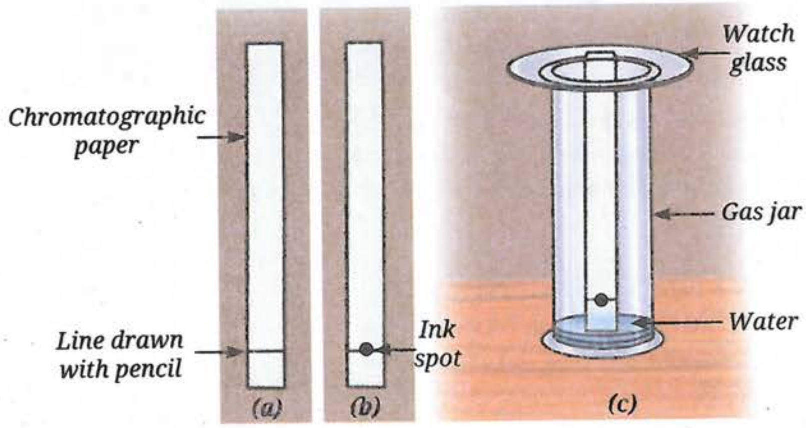


Fig. 5.15: Paper chromatography

3. Take enough water to make a thin layer at the bottom of a gas jar, a measuring cylinder, or a beaker.
4. Place the paper strip with the ink spot vertically into the container, so that its lower end dips into the water. The water level should be below the spot, as shown in Fig. 5.15c.
5. Observe the paper as the water rises through the paper. What do you notice?
6. As the water rises, the ink starts to separate into different colour spots. What can you infer from this?

This method of separating the components of a mixture is known as **paper chromatography**. It uses differences in the interactions of the components with the solvent and the paper to separate them. The liquid carries the substances up the paper, separating them based on how fast they move. You can also try this with green food colour instead of black ink and use a 2 % *m/v* salt solution as the solvent.

Similarly, you can separate different pigments present in the green extract of spinach leaves or coloured pigments from the flower petals. Will water work as a solvent in every case? In some cases, you may need to use a different solvent, such as alcohol or a mixture of solvents.

Pause and Ponder

6. State whether the following statements are True or False. Also, correct the False statements.
   (i) Salt can be separated from a salt solution by evaporation or distillation.
   (ii) Distillation can be used for separation of two liquids even when these have the same boiling point.
   (iii) In paper chromatography, the solvent level should be above the sample spot at the beginning of the experiment.
   (iv) Evaporation and crystallization are the same processes.

5.4 How Can We Separate the Components of Heterogeneous Mixtures?

5.4.1 Separation of two immiscible liquids

You have learnt about non-uniform mixtures. Have you noticed what happens when water falls into a container that has oil? The oil and water form separate layers. They do not mix and are called **immiscible** liquids. Similarly, sand and water do not mix, nor do iron filings and sulfur. These are examples of heterogeneous mixtures.

Grade 6 Curiosity Chapter 9

How can you separate the components of a mixture of two immiscible liquids?

Let us try to separate mustard oil from water.

Activity 5.6: Let us separate

1. Pour a mixture of 5 mL mustard oil and 20 mL water into a 50 mL separating funnel.
2. Let it stand undisturbed. What do you observe?
3. You will see the formation of two separate layers of mustard oil and water (Fig. 5.16). The yellow-coloured mustard oil forms the upper layer and water forms the lower layer. Can you explain why?
4. Open the stopcock of the separating funnel slowly to collect the lower layer of water carefully into a container.
5. Close the stopcock when the water is almost fully drained.
6. Collect the next small portion that may contain both liquids and discard it.
7. Collect the layer of oil separately by opening the stopcock again.

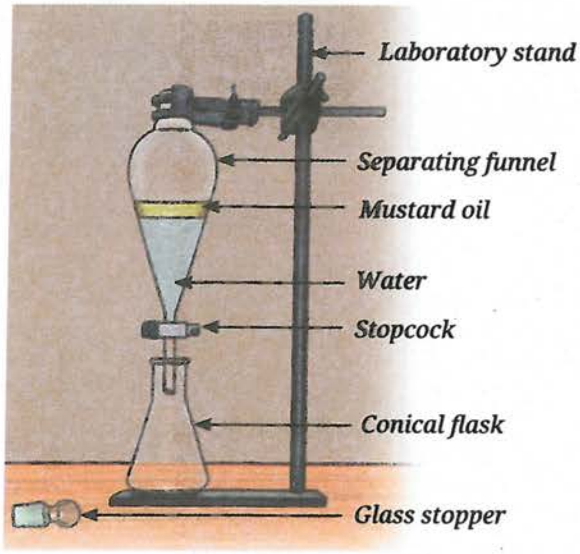


Fig. 5.16: Separation of immiscible liquids

You now have two separate liquids.

Can you think of any heterogeneous mixtures with a gas as one of the components?

Gas particles are free to move in all directions, so they mix easily and uniformly with other gases. Hence, most mixtures of gases are homogeneous, such as a mixture of hydrogen and oxygen, which is used as a rocket fuel. On the other hand, smoke (solid particles suspended in air), fog (tiny liquid water droplets present in air) and dust in the air are some heterogeneous mixtures with gas as one of the components.

What if...

two immiscible liquids of the same density are mixed in a separating funnel, how will the layers form?

Most of the solid-solid mixtures are heterogeneous. You can use a property of one of the solids to separate the mixture. You have learnt how to separate iron nails from sawdust using a magnet. Now, let us explore another technique to separate solid-solid mixtures.

Grade 6 Curiosity Chapter 9

5.4.2 Sublimation

Activity 5.7: Let us explore

1. Take a spatula full of the mixture containing crushed camphor and sand. Put it into a clean and dry china dish. Place it on the tripod stand using a wire gauze.

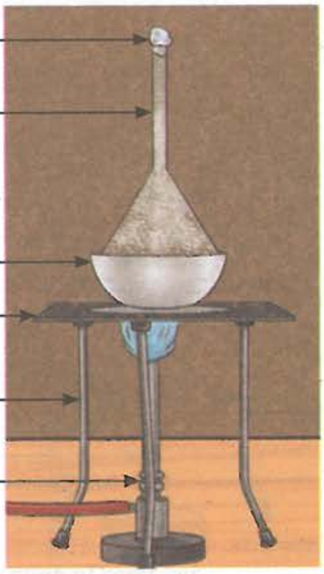


Fig. 5.17: Sublimation of camphor

2. Take a clean and dry glass funnel. Plug its nozzle with cotton.
3. Keep this funnel inverted on the china dish and set up the apparatus as shown in Fig. 5.17.
4. Light the burner and place it under the wire gauze.
5. Heat the china dish gently for a few minutes.
6. Observe the inner wall of the funnel carefully. Do you notice any solid deposits?
7. You may find white, solid camphor deposits on the inner wall of the funnel while sand remains in the china dish.

Camphor, on heating (below its melting point), changes directly from the solid state to the vapour state without passing through the liquid state, this process is called **sublimation**. On cooling, vapours condense back into a solid without becoming a liquid, this is called **deposition**. Hence, camphor sublimes and separates from sand because sand does not sublime on heating.

You can also perform this activity using any other sublimable substance, such as naphthalene, in place of camphor.

Similarly, solid carbon dioxide, known as dry ice which is used for ice cream storage, also undergoes sublimation. Can you think of any other mixtures where sublimation can be used to separate the components?

Is it possible to dissolve one metal in another?

Metals do not dissolve into each other at room temperature. However, when metals are melted at high temperatures, they can be mixed to form a solution. When such a hot mixture of two or more metals cools, it solidifies into a new material that appears to be a single metal. A homogeneous mixture of two or more metals, or a metal and a non-metal, is called an **alloy**. Physical methods cannot separate the components of an alloy. They are generally prepared to produce materials that are stronger, more rigid, or more corrosion-resistant. Common examples of alloys include brass — a mixture of approximately 80% copper and 20% zinc; bronze — a mixture of approximately 80% copper and 20% tin; stainless steel — usually a mixture of iron and other elements, such as carbon (about 0.03 – 0.8%), chromium (16 – 18%), nickel (10.0 –14.0%) and molybdenum (2.0 – 3.0%).

Pause and Ponder

7. Why do immiscible liquids form two separate layers in a separating funnel?
8. Is sublimation different from evaporation? Justify.

5.4.3 Suspensions

Let us look closely at the container shown in Fig. 5.2. No matter how well you stir, the sand particles can be seen clearly, unlike in a solution, where the solute particles are not visible. Such heterogeneous mixtures in which the solid particles (sand) do not dissolve but remain suspended throughout the bulk of the medium (water) are called **suspensions**. In the case of a suspension, the particles of the undissolved substance are larger in size than the particles present in the solution. Particles of a suspension are visible to the naked eye. Some other examples of suspension are sawdust suspended in water and tea leaves in water.

How can we separate mud from water?

If you leave a container of muddy water undisturbed, the heavier mud particles settle at the bottom and the water may still appear cloudy. You can filter the muddy water through a cotton cloth or filter paper. While some larger particles will be removed, the water often remains cloudy. This shows that filtration is not always enough to separate tiny particles. If the muddy water is still not clear even after keeping for some time, how can it be cleaned? In such cases, we use techniques, such as centrifugation and/or coagulation.

Let us explore these processes!

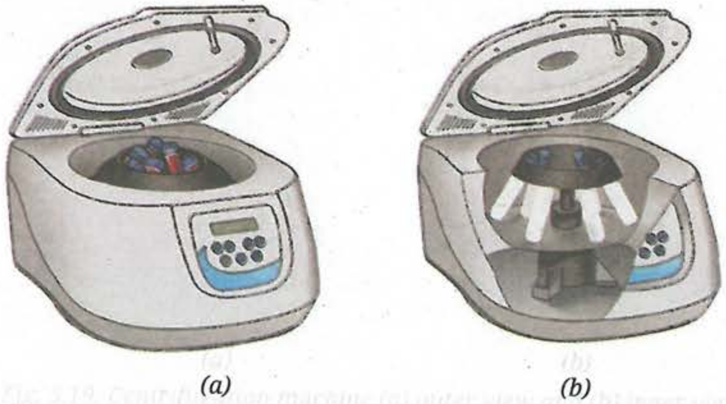
A. Centrifugation

Let us understand this by playing a game. Choose a partner. Then, cross your arms and hold each other's hands as shown in Fig. 5.18. Now spin around together. Do you feel as if you are being pulled outwards? A similar force helps to separate a mixture in a tube by **centrifugation**. This process involves spinning a mixture in a tube at a high speed (Fig. 5.19). During centrifugation, the tubes become horizontal and the centrifugal force (outward force acting on a body moving in circular motion) causes the heavier particles to move outwards, where they settle at the bottom of the tube, while the lighter liquid remains at the top.

Threads of Curiosity

The spinning game is a folk dance called *phugadi* in Marathi and *kikli* in Punjabi. What is this called in your local language?

Fig. 5.18: A spinning game



(a) (b)

Fig. 5.19: Centrifugation machine (a) outer view and (b) inner view

Centrifugation is widely used in laboratories to separate the components of blood, such as red blood cells and plasma and in many chemical industries.

Bridging Science and Society

The Paperfuge

Centrifugation is usually done using an electric machine but by applying ideas from a common toy, a simple hand-powered device called a paperfuge (Fig. 5.20) can perform the same process without electricity. By spinning the blood samples at a very high speed, the paperfuge separates heavier components from lighter ones, just like a laboratory centrifuge. This low-cost tool can help detect diseases like malaria and anaemia in remote areas. Find out more about such simple technological inventions that improve access to medical care in remote places.

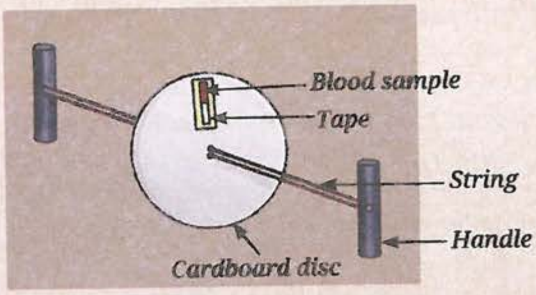
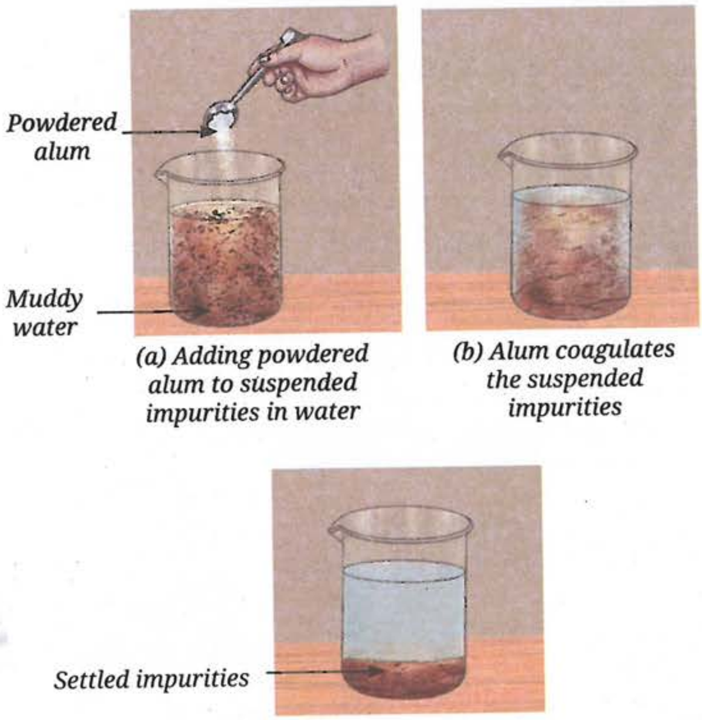


Fig. 5.20: Paperfuge



(a) Adding powdered alum to suspended impurities in water

(b) Alum coagulates the suspended impurities

(c) Impurities settle at the bottom

Fig. 5.21: Process of coagulation

Activity 5.8: Let us make a model

Make your own centrifuge with a cardboard disc and thick thread. You will be able to see how the heavier particles move outwards. It is a fun and hands-on way to understand the science behind separation. Which mixture would you like to separate using this mini centrifuge?

B. Coagulation

Powdered alum (*fitkari*) can be added to a beaker containing muddy water (Fig. 5.21a). Alum is a white crystalline chemical substance often used in water purification. The alum causes the fine suspended particles to clump together. This process is called **coagulation** and the alum is said to act as a **coagulant** (Fig. 5.21b). These larger clumps thus formed, settle by gravity (sedimentation), as shown in Fig. 5.21c and can be separated from water by decantation or filtration.

Can you think of any other coagulation processes used in everyday life?

The formation of cheese (*paneer*) from milk also involves coagulation, in which acid (lemon juice or vinegar) is used as a coagulant. It causes the coagulation of milk proteins, forming cheese.

5.4.4 Colloids

If the components of blood can be separated by centrifugation and the blood coagulates, is it a suspension? However, we cannot see blood cells with the naked eye. Is it a solution?

Blood is neither a solution nor a true suspension. It is a **colloid**. Some other examples of colloids are milk, tomato sauce and ice cream.

Bridging Science and Society

Donate Blood

Donating blood saves lives. People in emergencies, during surgeries, or with serious illnesses may need a blood transfusion, which is the transfer of blood from a healthy person to a patient.

Donated blood is tested and when the blood group is identified, it is separated into its components, such as plasma, platelets, white and red blood cells (Fig. 5.22). These are stored safely in blood banks and supplied when required. In Chapter 3, Tissues in Action, you have learnt that blood connects different parts of the body by transporting nutrients, gases and hormones.

The body replaces the donated blood naturally within a few weeks, making blood donation safe and helpful.

Do you know your blood group? Find out!

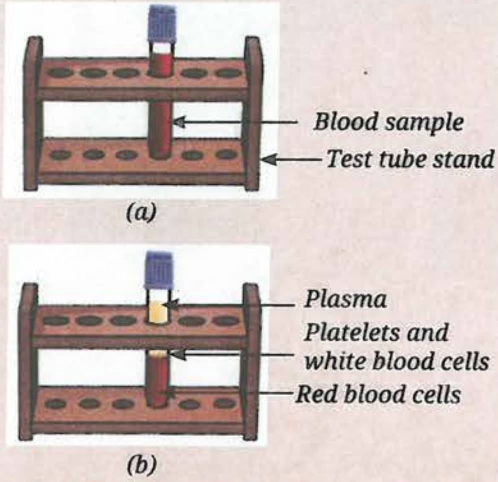


Fig. 5.22: Components of blood (a) before centrifugation and (b) after centrifugation

Let us try to understand what are colloids. How are they different from solutions and suspensions? Can you think of some other substances that could be colloids?

Solutions, suspensions and colloids (Fig. 5.23) differ mainly in the size of the dissolved or the suspended particles. The particle size of a solute is the smallest (less than 1 nm diameter) in a solution. Colloids have larger particles (1 – 1000 nm), while suspensions have much larger particles (more than 1000 nm in diameter).

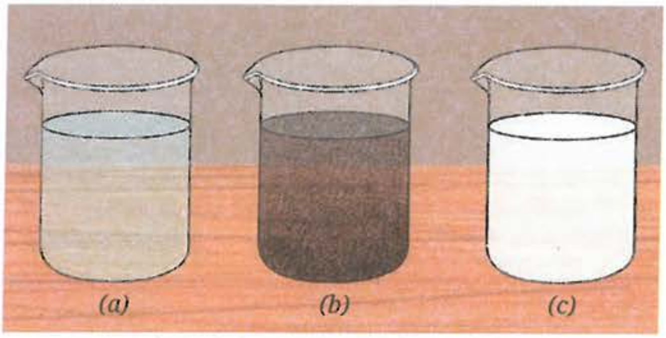


Fig. 5.23: (a) Solution, (b) suspension, and (c) colloid

Unlike suspension, the particles in a colloid do not settle over time from the mixture. They are uniformly dispersed throughout the mixture as in a solution.

5.5 Tyndall Effect

Let us go back to Activity 5.1. What happened to the thin beam of laser light when it was passed through the beakers containing the mixtures? You might have observed that the path of the light beam was not visible in solution A. The particles in suspension B scattered (spread) the beam of light making its path visible. In mixture C too, the path of light was visible, indicating that the particles scattered the light, though the mixture appeared homogeneous.

Have you ever observed light scattering by particles in your surroundings? The scattering of light by particles is known as the **Tyndall effect**. It is called so because it was first explained by the scientist John Tyndall, who studied the scattering of light by particles.

This effect can also be observed when a fine beam of light enters a dark room through a small hole. This happens because light gets scattered by

Fig. 5.24: Demonstration of Tyndall effect in a sports stadium

the dust and smoke particles in the air. You might have also observed this phenomenon in the floodlights in a sports stadium (Fig. 5.24). Think of some more examples!

Scattering of light occurs when it passes through a colloid or a suspension but not when it passes through a transparent solution.

The components of a colloid are called the dispersed phase and the dispersion medium. The solute-like component or the dispersed particles, in a colloid form the **dispersed phase** and the component in which the dispersed phase is suspended is known as the **dispersion medium**.

Threads of Curiosity

Some common colloids we encounter in our daily lives have both the dispersed phase and the dispersion medium as liquids. These are called emulsions. Emulsions containing oil and water are further classified as oil-in-water or water-in-oil, depending on the nature of the dispersed phase and the dispersion medium. Milk and vanishing creams are common examples of oil-in-water emulsions, whereas butter, body lotions, cold cream, etc., are examples of water-in-oil emulsions. Some medicines are prepared as emulsions to disperse them in water and make them easily palatable. This also reduces the greasy feeling of the liquid medicine.

The presence of emulsifying agents stabilises emulsions. For example, proteins in milk and butter act as emulsifying agents.

You can make an emulsion by thoroughly mixing and shaking a few drops of cooking oil with water containing a few drops of soap solution.

Pause and Ponder

9. Clouds are made up of tiny water droplets or ice crystals floating in the air. Based on what you know about solutions, suspensions and colloids, what type of mixture do you think clouds are and why?
10. Why do cities with a lot of smoke and dust in the air often look hazy?

Activity 5.9: Complete Table 5.1 and review what you have learnt about solutions, suspensions and colloids.

Table 5.1: Properties of different types of mixtures

S. No.	Property	Solution	Suspension	Colloid
1.	Nature (homogeneous/heterogeneous)			
2.	Particle size			
3.	Visibility			
4.	Separation by filtration			
5.	Settling			
6.	Tyndall effect			

We use various properties, such as size, density and solubility to separate mixtures. However, separation is not always simple. Imagine trying to separate all the ingredients in a lemonade once they have been mixed. Can you do it?

Do you know that separation happens in nature and in our bodies, too? For example, our kidneys remove waste from our blood. Today, we face bigger challenges like cleaning oceans and rivers by removing plastic waste. It is also essential to treat sewage water before releasing it into the environment. Sewage treatment involves steps, such as sedimentation, coagulation and filtration. Clean water obtained in this way can be reused for flushing toilets or watering plants.

Another important task is sorting or segregating the waste at home. Dry waste, such as plastic, paper, glass and metal can be recycled, while wet waste like food scraps, vegetable peels, etc., can be composted. Researchers are also finding ways to recover valuable materials, such as lithium from old batteries used in mobile phones and laptops.

By improving the methods for separating waste and recycling materials, you can help make the world cleaner, healthier and more sustainable.

At a Glance

- Mixtures are classified as homogeneous or heterogeneous and also as solutions, suspensions, or colloids.
- Separation of mixtures is a crucial process for obtaining pure substances.
- Crystallization is a technique used to get a pure solid from its saturated solution.
- Distillation is used to separate two miscible liquids with a minimum difference of 25 °C in boiling points. It can also be used to obtain a liquid from a mixture of a liquid and a solid.
- Paper chromatography can be used to separate compounds by taking advantage of differences in their rates of movement on the paper.
- A separating funnel is used to separate two immiscible liquids based on their different densities.
- The transition of a solid directly into a vapour (below its melting point) without passing through the liquid state is called sublimation. The process when the vapour cools and changes back into a solid without becoming a liquid is called deposition.
- Centrifugation uses rapid spinning to separate heavier solid particles from a solid-liquid mixture.
- Coagulation involves the addition of a substance, called a coagulant, to make smaller particles clump together and settle down in a heterogeneous mixture of solids and liquids.
- The dispersed particles in a colloid or suspension scatter light, which is known as the Tyndall effect.

Revise, Reflect, Refine

1. Which of the following mixtures are correctly classified as homogeneous (Hm) and heterogeneous (Ht)? Choose the correct option.
   (i) Air — Hm, Milk — Ht, Sugar solution — Hm, Smoke — Hm
   (ii) Brass — Ht, Fog — Ht, Vinegar — Ht, Muddy water — Hm
   (iii) Copper sulfate solution — Hm, Salt solution — Hm, Milk — Hm, Bronze — Hm
   (iv) Muddy water — Ht, Milk — Ht, Blood — Ht, Brass — Hm
2. Choose the correct options, and explain the reason for the correct and incorrect options.
   Which among the following mixtures show the Tyndall Effect? A mixture of:
   (a) air and dust particles
   (b) copper sulfate and water
   (c) starch and water
   (d) acetone and water
   (i) a and b (ii) b and d (iii) a and c (iv) c and d
3. A mixture can be categorised as a solution, a suspension, or a colloid, each possessing distinct properties. Utilise the words or phrases provided in the box to fill in the Table 5.2. Words and phrases may be used more than once.

Words and Phrases
Large-sized particles; Particles remain evenly distributed; Small-sized particles (less than 1 nm diameter); Moderate-sized particles (1 – 1000 nm); Settles down when left undisturbed (more than 1000 nm in diameter); Does not settle down; Scatters light; Separates by filtration; Transparent; Salt solution; Milk; Sand in water; Smoke; Heterogeneous mixture; Cannot be separated by filtration; Mud; Butter; Brass.

Complete the Table 5.2.

Table 5.2

Solution	Suspension	Colloid
Properties ______ ______	Properties ______ ______	Properties ______ ______
Examples ______ ______	Examples ______ ______	Examples ______ ______

4. Solve the following problems:
   (i) A cake recipe uses dry ingredients, namely 75 g of sugar for 420 g of all-purpose flour and 5 g of sodium hydrogencarbonate. Express the concentration of each component in the mixture using an appropriate method.
   (ii) A brass alloy contains 70% copper by mass. Calculate the quantities of copper and zinc present in 120 g of brass.
5. The label on a cooking oil pack says one litre (910 g). If this oil is mixed with water, will it form a separate layer? If so, which substance will be on top? How will you separate the two layers? Also, draw the diagram of the apparatus used.
6. 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.

   Choose the correct option:
   (i) Both A and R are true, and R is the correct explanation of A.
   (ii) Both A and R are true, but R is not the correct explanation of A.
   (iii) A is true, but R is false.
   (iv) A is false, but R is true.
7. How would you separate the mixtures given in Table 5.3? Mention the reason for choosing your method. If a mixture cannot be separated, explain why.

Table 5.3

Mixture	Method of separation	Reason for selection
Mud from muddy water		
Plasma from other components in the blood sample		
Naphthalene and sand		
Chalk powder and common salt		
Common salt and water		
Oil from water		
Pigments of the flower		

8. Two miscible liquids, A and B, are present in a mixture. The boiling point of A is 60 °C and the boiling point of B is 90 °C. Suggest a method to separate them. Also, draw a labelled diagram of the method suggested.
9. Compare evaporation, crystallization and distillation. In which situation, would you prefer each of these over the others?
10. Blood is an example of a colloidal mixture. (i) What would happen if blood behaved like a true suspension inside the body? (ii) In a blood sample, identify the dispersed phase and the dispersion medium.

11. You are given a mixture of sand, common salt and naphthalene (Fig. 5.25a). The Fig. 5.25b depicts various steps used to separate the components of this mixture. Identify and write down the correct sequence of separation techniques.

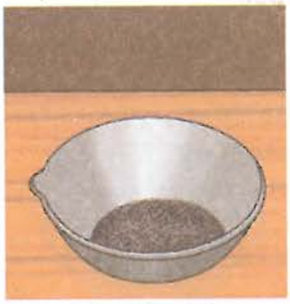


Fig. 5.25: (a)

1 2 3

Fig. 5.25: (b)

12. Why is distillation an effective method for separating a mixture of water and acetone?
13. Answer the following questions with the help of the data given in Table 5.4.

Table 5.4: Solubility of various salts (in g per 100 g of water) at different temperatures

Salts	Temperature (°C)					
	10 °C	20 °C	30 °C	40 °C	60 °C	80 °C
Potassium nitrate	21	32	45	62	106	167
Sodium chloride	36	36	36.3	36.5	37	37
Potassium chloride	35	35	37.4	40	46	54
Ammonium chloride	24	37	41	41	55	66

(i) What mass of potassium nitrate would be needed to prepare its saturated solution in 50 g of water at 40 °C?

(ii) A student makes a saturated solution of potassium chloride in water at 80 °C and leaves the solution to cool at room temperature (25 °C). What would she observe as the solution cools? Explain.

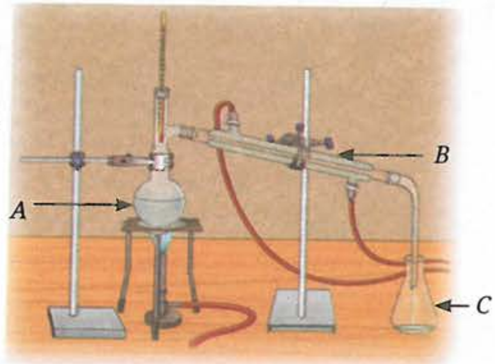
(iii) What is the effect of a change in temperature on the solubility of salts? Also, compare the changes in the solubility of the four given salts with increasing temperature from 10 °C to 80 °C.

14. Three students, A, B and C, are preparing sugar solutions for an experiment:
- Student A dissolves 20 g of sugar in 80 g of water.
- Student B dissolves 20 g of sugar in 100 g of water.
- Student C dissolves 30 g of sugar in 80 g of water.

(i) Calculate the mass percentage (% *m/m*) concentration of sugar in each student's solution.

(ii) Whose solution is the most concentrated? Explain why.

15. Examine Fig. 5.26.
 (i) Identify the separation technique marked as 'S'.
 (ii) Label the apparatus A, B and C.
 (iii) Which of the following mixtures can be separated by the technique identified above? Use the data given in Table 5.5. Mixtures:
 (a) water — acetone (b) water — salt
 (c) acetone — alcohol (d) sand — salt
 (e) alcohol — chloroform (f) alcohol — benzene



S ....

Fig. 5.26

Table 5.5: Boiling points of some compounds

Solvent	Water	Acetone	Alcohol	Chloroform	Benzene
Temperature (°C)	100 °C	56 °C	78 °C	61 °C	80 °C

The Journey Beyond

- Demonstrate the Tyndall effect using different colloids. Create a series of experiments showcasing how light scatters in colloids making the beam visible. Use laser pointers (**Safety first:** Use it under the supervision of an adult), flashlights, or other light sources for your demonstrations.
- Make crystals of different compounds (common salt, epsom salt, sugar, borax, nickel sulfate, etc.). Observe them under a magnifying glass or a microscope. Note down their colours and shapes.
- Do red leaves also contain green pigments? Investigate it using paper chromatography.
- You can try chromatography to find the number of components present in a food colour (green, orange, yellow, etc.) or in coloured mouth fresheners (fennel seeds).
- Design an educational game where players identify and apply separation techniques to different mixtures through interactive challenges and hands-on activities.
- If you are camping outdoors and running short on clean water, you can obtain clean water by distillation. Can you think of a set-up with the items available to you?
- To learn more about the states of matter and concentration of solutions, you can explore the links given below:
  - https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html
  - https://phet.colorado.edu/sims/html/concentration/latest/concentration_all.html

The Quest Continues ...

Can we create artificial blood that works just as real blood for all patients?

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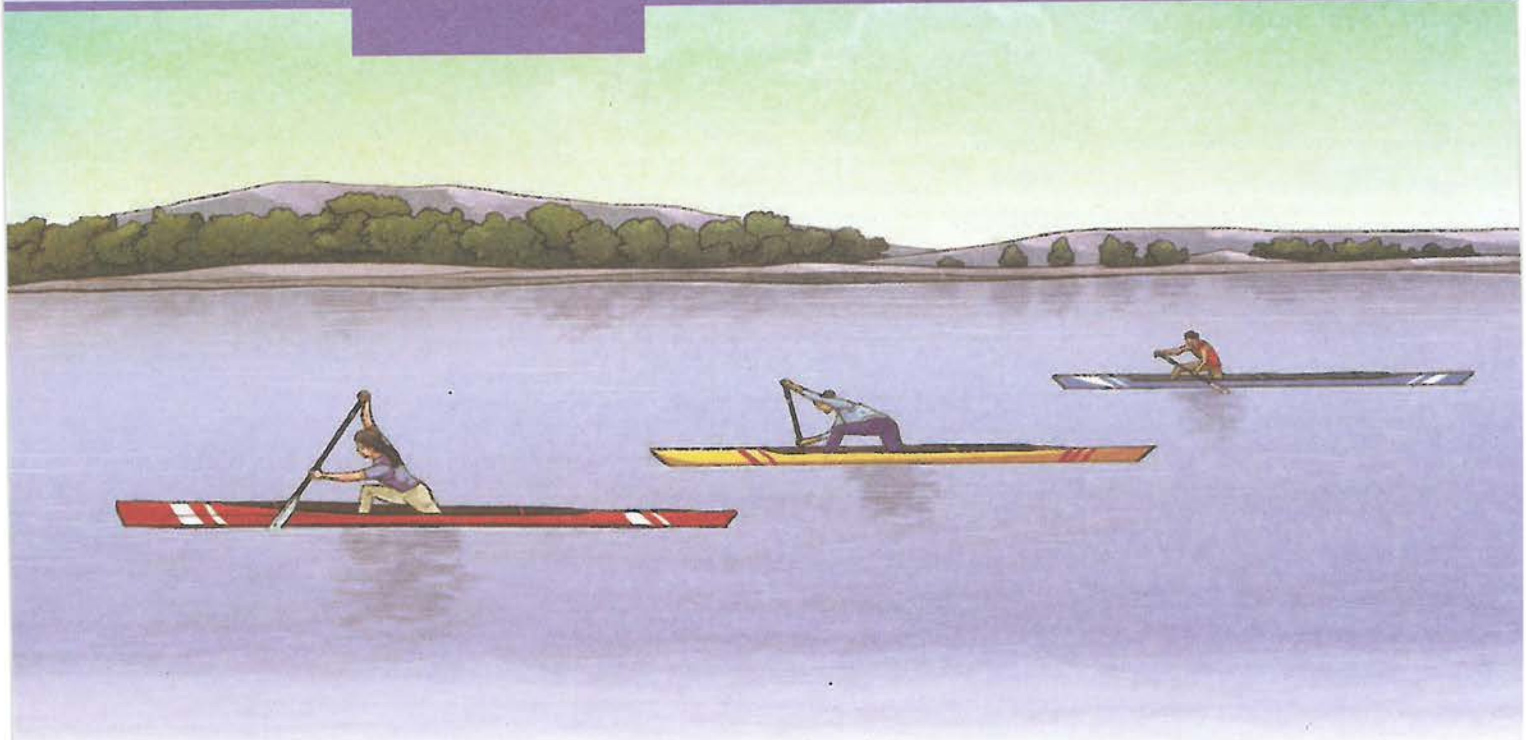
Chapter 6

How Forces Affect Motion



Think It Over

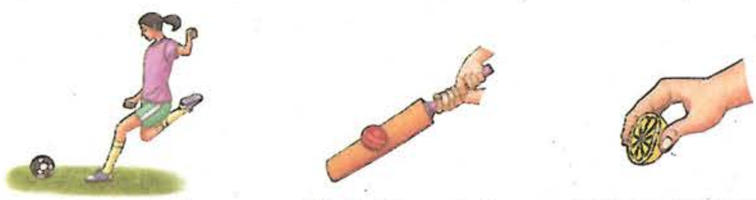
- Why does a canoe move forward when the canoeist pushes water backwards with their paddle and why does it move faster when they push harder?
- Suppose the same canoeist uses the same paddle force in two different canoes, one empty and one carrying another passenger. In which case will the canoe move faster?

In Chapter 4, you learnt to describe the motion of an object in terms of its position, velocity and acceleration. But you did not consider what causes motion. Is there an underlying cause for a change in position and velocity of an object? What is the nature of this cause? Do all motions require a cause? In this chapter, we will investigate what causes changes in the motion of objects. We will also discuss Newton's three laws of motion and learn how to apply them.

6.1 The Concept of Force

Grade 8 Curiosity Chapter 5

You may recall learning earlier that a force can make an object move from rest, change the speed and direction of motion of a moving object, and can even change the shape of an object. For example, a ball at rest starts moving when you apply a force, a force applied by a cricket bat on a cricket ball changes its direction, and a lemon can be squeezed by the force applied by your fingers (Fig. 6.1).



(a) Kicking a ball *(b) Striking a ball* *(c) Squeezing a lemon*

Fig. 6.1: Applying force on different objects

While learning about force earlier, did you **notice** that whenever any type of force acting on an object was described, its direction was also **specified**? For example, the phrases used were, force of friction acting on an object in a direction opposite to the direction of its motion; like poles of a magnet repelling each other or unlike poles attracting each other due to the magnetic force; like charges repelling or unlike charges attracting each other due to the electrostatic force; the Earth attracting objects towards itself due to the gravitational force; buoyant force exerted by liquid in an upward direction on an object placed in it, and so on. **Force** is a physical quantity for which we need to specify **direction** along with its **magnitude** and unit, just like for the physical quantities—position, displacement, velocity and acceleration of an object which were introduced in Chapter 4. The **SI unit of force is newton** (written with a small 'n') and its symbol is N. The magnitude of the force expresses its strength.

Grade 6 Curiosity Chapter 4

Grade 8 Curiosity Chapter 5

Note

If either the magnitude or direction, or the both, of a force applied on an object changes, the effect of the force also changes.

6.1.1 Measuring the magnitude of a force

How can we **measure** the magnitude of a force? Do you remember using a spring balance earlier to measure the weight of objects (Fig. 6.2)? Do you also remember that the weight of an object is the gravitational force with which the Earth pulls the object? A spring balance can be used to measure not just the weight of an object but the magnitude of the force in general. If you pull on the free end of the spring balance, it measures the force with which you pull on the spring inside the balance.

Grade 8 Curiosity Chapter 5

Fig. 6.2: Measuring the weight of an object using a spring balance

Threads of Curiosity

In everyday life, the smallest forces we can directly feel are of the order of millinewtons (10^{-3} N), such as a light touch. Scientists, however, can measure forces far smaller than this, down to yoctonewtons (10^{-24} N) in specialised experiments (as of 2026).

6.2 Balanced and Unbalanced Forces

In real life, situations seldom exist where only one force acts on an object. Usually, there is more than one force acting on an object. For example, when you are pushing a box placed on a surface then, apart from the force with which you are pushing it, the force of friction is also acting on the box in the direction opposite to that of the motion (Fig. 6.3a).

Fig. 6.3: (a) Pushing a box kept on table or floor

Or, take the example of a ball floating on water (Fig. 6.3b). Two forces are acting upon it—gravitational force by the Earth acting downwards and buoyant force applied by the liquid acting upwards. In such cases, what is the effect of forces when more than one force is acting on an object at rest or in motion?

Fig. 6.3: (b) A ball floating on water

Have you ever played a game of tug of war where two teams pull at a rope in opposite directions? If both the teams pull the rope with equal

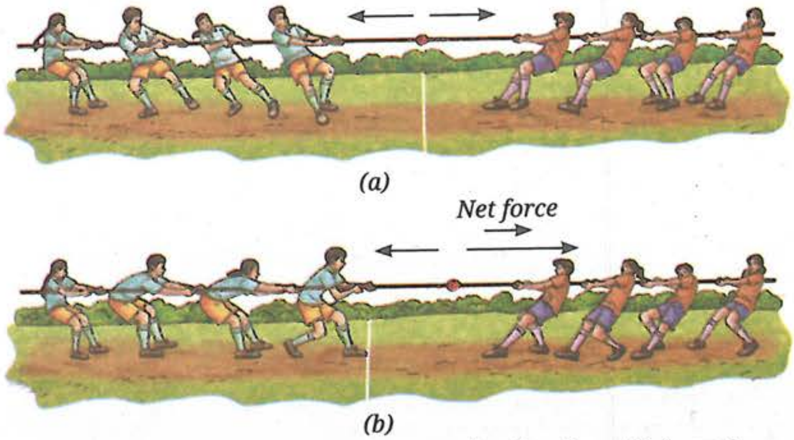


Fig. 6.4: Two forces applied in opposite direction of (a) equal magnitudes, (b) unequal magnitudes

force, the rope does not move (Fig. 6.4a). Such two forces, which are equal in magnitude but opposite in direction are called **balanced forces**. However, if one team pulls harder, i.e., it applies a force of larger magnitude, the forces are no longer balanced and the rope moves in the direction of the larger force (Fig. 6.4b). The rope does not move if the forces applied on it are balanced but moves if the forces are unbalanced.

If the forces applied on an object are not balanced, a non-zero **net force** acts on the object. When two forces are opposite in direction but unequal in magnitude (Fig. 6.4b), the magnitude of net force is equal to the difference between the magnitudes of two forces and the direction is along the force of the larger magnitude.

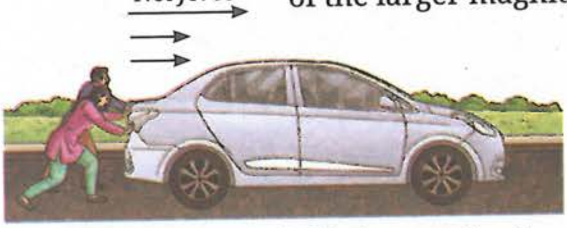


Fig. 6.5: Two forces applied in the same direction

Now, think of a situation where two people are applying forces in the same direction on a stalled car to make it move (Fig. 6.5). In this case, the magnitude of the net force applied by them on the car is the sum of the magnitudes of two forces. The direction of the net force is in the same direction as the two individual forces.

Example 6.1: Two forces of 10 N and 6 N are acting on a block lying on the table as shown in Fig. 6.6. What is the magnitude and the direction of the net force acting on the block in each case?

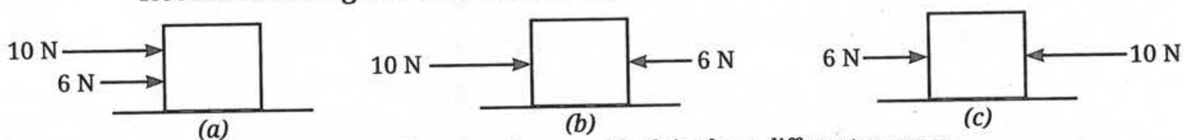


Fig. 6.6: Two forces acting on a block in three different manner

Answer:

(a) Net force = 10 N + 6 N = 16 N, acting towards the right side.
(b) Net force = 10 N – 6 N = 4 N, acting towards the right side.
(c) Net force = 10 N – 6 N = 4 N, acting towards the left side.

Ready to Go Beyond

There are situations in which forces do not act parallel or opposite to each other but act at an angle to each other. You will learn in higher grades how to calculate the net force in such cases. Also, there are situations where equal and opposite forces are applied to the two ends of an extended object which make the object rotate (Fig. 6.7). For example, applying equal and opposite forces to a handlebar or a tap makes it turn. You will also learn about this in higher grades.

Next Level Up

Fig. 6.7: Equal and opposite forces on an extended object

Pause and Ponder

1. A weightlifter lifts a barbell (Fig. 6.8). List two forces that are acting on the barbell. Are these forces balanced if the weightlifter keeps the barbell steady?
2. Two players R and S are participating in an arm-wrestling match (Fig. 6.9). At the instant, when the arms tilt to the front direction (out of the page towards you), are the forces exerted by the players balanced? If not, which player exerted the larger force?

Fig. 6.8: A weightlifter lifting barbell

Fig. 6.9: Arm-wrestling match

6.3 The Force of Friction: Often Overlooked but Always Present

Grade 8 Curiosity Chapter 5

You have learnt about the force of friction in an earlier grade but now let us learn more about it. Suppose an object is kept at rest on the floor and you apply a force on it in the forward direction (Fig. 6.10). Will the force applied by you make the object move? Many a times, you might have experienced that on applying a force on an object, it did not move and you had to apply a larger force to move it. Why is it so?

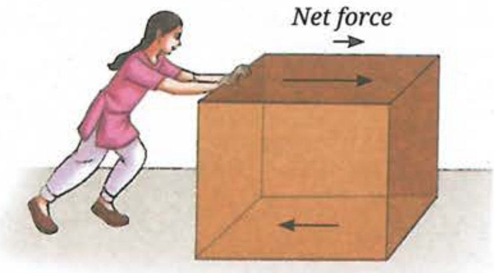


Fig. 6.10: A box being pushed

It is due to the force of friction arising between the bottom surface of the box and the floor acting in a direction opposite to the direction of the force applied by you. The box will start moving when the force applied by you is of larger magnitude than the force of friction, so that a net force acts on the box in the direction of its motion.

Note

Multiple forces may act on an object but its motion depends only on the net force.

Ready to Go Beyond

For an object being pushed, apart from the applied force and the force of friction, some other forces may also be acting on it (Fig. 6.11). One of these is the gravitational force (weight) and the other is the force exerted by the surface on which it is placed called the normal force. The weight acts in the downwards direction, whereas the normal force acts in the upward direction perpendicular to the surface. However, the two forces are balanced.

Air around the object also exerts a force of friction on the box when the box moves through the air, but in many cases its magnitude is so small that it can be neglected.

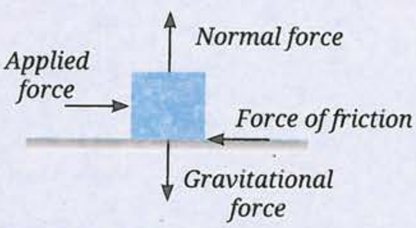


Fig. 6.11: Forces acting on an object

For the situation shown in Fig. 6.10, once the box starts moving and you stop applying the force on it, the box slows down and comes to a stop. You must have experienced this in many cases around you. You stop pedalling a bicycle and after some time it comes to rest after travelling some distance. You stop pushing a ball and it also comes to rest after travelling some distance. Does it mean that you need to continuously apply a force to keep

What if ...
the force of friction disappears in the world? How will the motion of objects be impacted?

it moving? On a moving object, we have to continuously apply a force to counter the force of friction. Otherwise, the force of friction acting against the direction of motion brings the object to rest.

Do you remember doing an activity in an earlier grade where you found that the force of friction depends upon the nature of the surfaces in contact? Let us carry out a similar activity here.

Grade 8 Curiosity Chapter 5

Activity 6.1: Let us investigate

1. Collect four coins of ₹ 10, one large strong rubber band and an adhesive tape. Locate horizontal surfaces of different materials, such as wooden table top, cemented floor, laminated table top, and polished marble or tiled floor (you may also choose other surfaces). Check that the surfaces are levelled.
2. Stack the four coins on top of each other and secure them together with an adhesive tape around the sides.
3. Hold the rubber band slightly stretched between your forefinger and thumb on the wooden table top (Fig. 6.12a). Mark points A and B at its ends as shown in Fig. 6.12b. Make another mark C up to which you will stretch the rubber band.

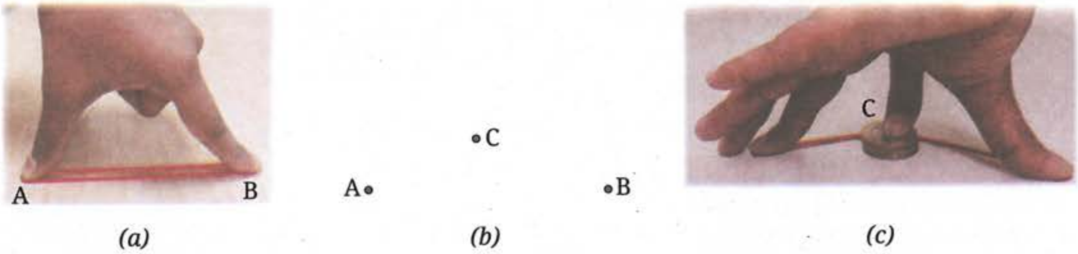


Fig. 6.12: (a) Rubber band slightly stretched between your forefinger and thumb, (b) marks A, B, C on the surface, and (c) rubber band stretched back to point C with stack of 4 coins

4. Holding the ends of the rubber band at A and B, place the stack of coins near the middle of A and B. Now, using a finger of your other hand, push back the stack of coins till the rubber band is pulled back to the mark C (Fig. 6.12c). Then, release the stack of coins and **observe** its motion. Do you find that after losing contact with the rubber band, the velocity of the stack of coins decreases gradually and it comes to rest after travelling some distance? Measure the distance travelled from C and record it. Repeat this step twice.
5. Repeat steps 3 and 4 for laminated table top while ensuring that the points A, B and C are marked at the same distances as earlier. Does the stack of coins travel a larger distance than it did on the wooden table top before coming to rest? Does its velocity decrease more slowly now?
6. Next, repeat step 5 on a horizontal polished marble or tile floor. Does the stack of coins travel an even larger distance and its velocity decrease even more slowly? What conclusion do you draw from your observations?

Before you release the stack of coins, it is stationary. It means that the forces acting upon it are balanced. Upon release, the force applied by you vanishes and the force applied by the stretched rubber band in the forward direction on the stack of coins sets it moving. The coins start moving means that the force applied by the rubber band is larger than the force of friction and a net force acts on stack of coins in the forward direction (Fig. 6.13a). Due to the net force, the velocity of stack of the coins changes from zero to a certain value, i.e., the net force provides an acceleration in the forward direction.

However, the moment the stack of coins loses contact with the rubber band, the force due to the rubber band is no longer acting upon it. But the force of friction continues to act upon the stack of coins in the direction opposite to their motion (Fig. 6.13b). It gradually decreases its velocity and finally brings it to rest.

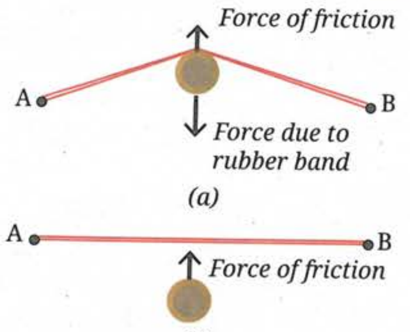


Fig. 6.13: Force acting on the stack of coins (a) due to the stretched rubber band and friction upon release of rubber band, and (b) only due to friction

Even though the rubber band is stretched by the same amount in each case, the distance travelled by the stack of coins on different surfaces changes. This indicates that the force of friction on these surfaces is different. But how can you check if the force of friction is indeed different for different surfaces?

Activity 6.2: Let us measure

1. Take a spring balance and a wooden block.
2. Place the spring balance in a horizontal position on one of the surfaces used in Activity 6.1 and check that its scale reading is zero. Attach the wooden block to the hook of the spring balance as shown in Fig. 6.14.

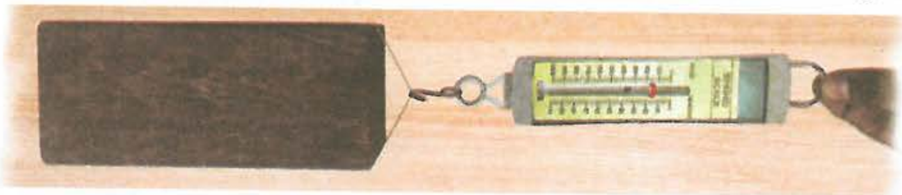


Fig. 6.14: A block being pulled by a spring balance

3. Pull the spring balance by gradually increasing force and note down the reading on it when the block just starts moving. What does this reading indicate? The forces acting on the block are the force applied by the spring on it and the force of friction. If the velocity of the block is neither increasing nor decreasing, what can you say about the net force acting on the block? Does the reading of the spring balance indicate the magnitude of the force of friction acting on the wooden block?
4. Now repeat step 3 on the remaining three surfaces from Activity 6.1.
5. **Compare** the readings of the spring balance for all surfaces. Are the readings different? Is the reading smallest for the surface on which the stack of coins travelled the largest distance? Is the reading largest for which the distance travelled was the smallest?

The reading of the spring balance gives an approximate measure of the force of friction acting between the surface of the block and the surface on which it moves. A smaller reading indicates a smaller force of friction, while a larger reading indicates a larger force of friction. From Activities 6.1 and 6.2, we **conclude** that when the force of friction is smaller, the velocity of the stack of coins decreases more slowly and it travels a larger distance before coming to rest.

Think as a Scientist

Now, conduct a thought experiment. We do a thought experiment when the conditions required for the experiment are difficult to recreate in the real world. Suppose, you find an object and a horizontal floor having such smooth surfaces that the force of friction between them is zero. Imagine, what will happen if you repeat steps 3 and 4 of Activity 6.1 with such an object and a horizontal floor? Will the velocity of the object decrease? Will the object ever come to rest or continue moving forever?

Meet a Scientist

In ancient times, it was well recognised that a force was required to move a stationary object or to stop a moving object. But was a force required to keep an object moving with a constant velocity? For ages, it was mistakenly thought that a force was indeed required to maintain an object in such a motion. It was only in the 17th century that **Galileo Galilei** argued through a series of thought experiments that if a body moves along a horizontal plane and all impediments to its motion are removed, it will continue to move indefinitely.

Meet a Scientist

Isaac Newton used the word 'inertia' to describe the tendency of objects to resist change in their state of rest or uniform motion, and used this idea to frame his first law of motion. Along with this, Newton presented two more laws of motion in 1687. The formulation of these three laws of motion was a defining moment in the history of science. The unit of force is named after Newton. Remember that when a unit is named after a person, its full form begins with the small case (newton and not Newton) while its symbol is capitalised (N and not n).

6.4 Newton's First Law of Motion

Newton's first law of motion can be stated as:

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

In other words, we can say that if the net force acting on an object is zero, the body cannot begin to move or change its velocity. In such a case, its acceleration is zero.

Note

An object at rest means that it has zero velocity. Remember that constant velocity means that there is no change in the magnitude or the direction of velocity. If this constant velocity is non-zero, the motion is in a straight line in the same direction and the magnitude of velocity remains the same.

Example 6.2: A person is exerting a force on a moving box in the forward direction which is equal to the force of friction acting between the bottom surface of the box and the floor. Will the box continue moving or will it come to rest after some time?

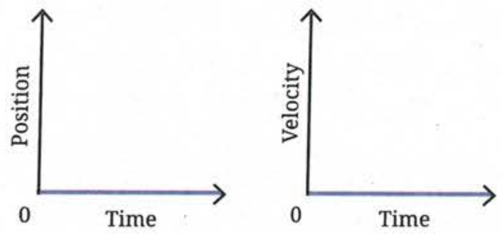
Answer: The force of friction will be acting on the box in the backward direction. The two forces acting on the box are equal and opposite, and thus, they balance each other. The net force acting on the box is zero and as per the Newton's first law of motion, the box will continue moving with constant velocity.

Example 6.3: Draw (i) position-time, and (ii) velocity-time graphs for an object on which no net force is acting.

Answer: When no net force is acting on an object, there are two possibilities — either the object is at rest or the object is moving with a constant velocity. If the object is at rest, its position will not change with time and its position-time graph is as shown in Fig. 6.15a. Its velocity will remain zero and its velocity-time graph is shown in Fig. 6.15b. If the object is moving with constant velocity and no net force is acting upon it, it will continue moving with the same velocity and the velocity-time graph is shown in Fig. 6.16b. The position-time graph will be a straight line as shown in Fig. 6.16a.

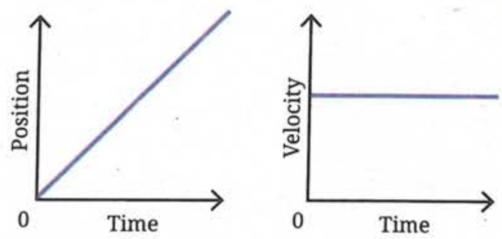
Note

If the force of friction is zero, a net force will have to be applied to an object at rest to set it moving. But once the object is moving, no further force is required to keep it moving with a constant velocity. However, to change the velocity (magnitude or direction), or to stop a moving object, a force will have to be applied.



(a) (b)

Fig. 6.15: When the object is at rest, its (a) position-time graph, (b) velocity-time graph



(a) (b)

Fig. 6.16: When the object is moving with a constant velocity, its (a) position-time graph, (b) velocity-time graph

Pause and Ponder

3. An object is moving with a constant velocity. Is there a net force acting upon it?
4. Suppose, no net force is acting on an object. Which of the following situations are possible?
   (i) Object remains at rest if at rest.
   (ii) Object keeps moving with a constant velocity if already moving.
   (iii) Object is moving with a constant acceleration.
5. In the real world, it is difficult to find a situation where no forces are acting on an object. But by applying additional forces, a condition can be achieved where the net force on the object is zero. Explain with the help of an example.

Newton's first law of motion describes the motion of objects in the absence of a net force. It is natural to ask what happens to the motion of an object when there is a net force acting upon it. Newton's second law of motion addresses this issue.

6.5 Newton's Second Law of Motion

You know that a force can set an object in motion, bring it to rest, or change its velocity. A change in velocity means that the object is accelerating. Thus, a force produces acceleration. But what is the relationship between the net force acting on an object and its acceleration?

Think as a Scientist

From our everyday experiences, you know that if a ball is pushed gently, it moves slowly starting from rest, i.e., the acceleration due to the force applied by you is small. On the other hand, a strong push results in the ball starting to move fast, i.e., a larger acceleration due to the force applied by you. So based on your experiences, you can make a hypothesis — for the same object, a larger force results in larger acceleration (or a smaller force results in smaller acceleration). Now, how can you test your hypothesis? You will have to think of an activity where you can apply forces of different magnitudes on the same object and the same surface to find the resultant acceleration. How can you apply forces of different magnitudes? You have learnt in earlier grade about gravitational force with which the Earth pulls an object towards itself. It is called the weight of an object and is different for different objects. Hence, you can use weights of different magnitudes to apply forces of different magnitudes.

Grade 8 Curiosity Chapter 5

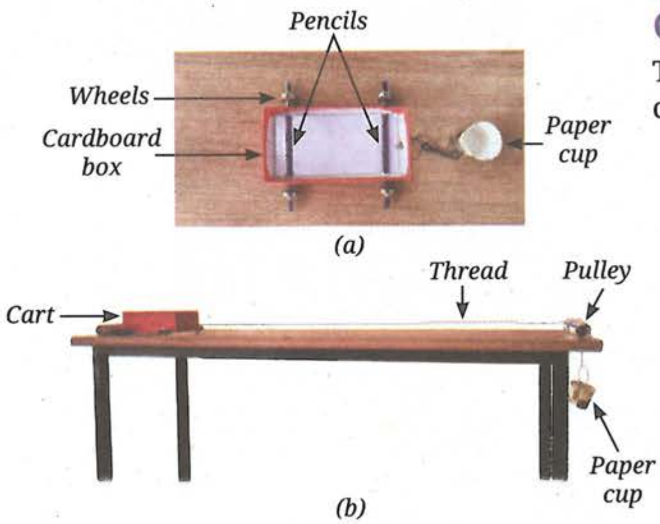


Fig. 6.17: (a) A cart, (b) a cart and pulley system

Activity 6.3: Let us experiment (Demonstration activity)

This activity is recommended to be performed as a classroom group activity facilitated by the teacher.

1. Take four ball bearing wheels, two pencils, an empty cardboard box (to make a cart), a paper cup, a piece of pipe (to use as a pulley), a length of thread, some coins or other objects (to place in cup) and a weighing scale to measure mass.
2. Insert two pencils through the sides of the box near the bottom, to function as axles and attach a wheel to each of their free ends as shown in Fig. 6.17a (if the wheels are loose, wrap some adhesive tape at the pencil ends to fit the wheels tightly). Attach a thread to the front end of the box with which you can pull the cart.
3. Draw a line at one end of the table, which will mark the starting point for the cart. Put the thread over a small pipe attached at the other end of the table (Fig. 6.17b). To this thread attach a cup in which you can put some objects. As you let the system go, the cup will move down due to the gravitational force by the Earth on it, and the thread will pull the cart with a constant force.
4. Measure the mass of the cup along with any other objects put inside it with the weighing scale.
5. Start recording a video of the cart in slow motion. Release the cart from the start line, and record the video until it reaches the pipe at the other end of the table.

6. Read the time when you released the cart and when it reached the end of the table by seeing the slow-motion video and record the difference as time T_1.
7. Now double the mass of the cup with the objects inside it, and repeat steps 5 and 6 to record the time difference T_2.

Using the values of the time measured, let us do some analysis. For both cases, the cart starts with zero velocity $u = 0$ and travels the same distance s. If a_1 and a_2 are the accelerations in the two cases respectively, using kinematic equation, we obtain

$$s = \frac{1}{2} a_1 T_1^2 \qquad \text{and} \qquad s = \frac{1}{2} a_2 T_2^2$$

Equating the two equations, we obtain

$$\frac{a_1}{a_2} = \frac{T_2^2}{T_1^2}$$

Substituting the values of T_1 and T_2, you find that when you increased the force for the same mass of the cart the acceleration increased.

You may conclude that the acceleration of an object of fixed mass increases as the net force applied on it increases.

Think as a Scientist

Apart from force, does acceleration depends on any other factor? From everyday experiences, you know that with the same magnitude of force, it is easier to set lighter objects in motion than heavier ones. This leads to a second hypothesis, that for the same force, a smaller mass has a larger acceleration (or a larger mass has a smaller acceleration). Now how can you test your second hypothesis?

Activity 6.4: Let us experiment (Demonstration activity)

This activity is recommended to be performed as a classroom group activity facilitated by the teacher.

1. Repeat Activity 6.3 with a variation. Keep the mass of the cup and objects inside it constant. Double the mass of the cart by adding more objects in it.
2. Measure the mass of the cart along with the objects inside it with a weighing scale.
3. Carry out steps 5 and 6 of Activity 6.3.

Using the values of time measured, find the ratio of acceleration for these two cases. Do you find that for the same force, when you increased the mass of the cart, the acceleration decreased? This means that for a given magnitude of a force, the acceleration produced is inversely related to the mass of the object.

The relation between force, mass and acceleration is expressed in the Newton's second law, one of the most fundamental ideas in all of science. **Newton's second law of motion** can be stated as:

When a net force acts on an object, the object accelerates in the direction of the net force. The magnitude of the acceleration is proportional to the magnitude of the net force and is inversely proportional to the mass of the object.

Mathematically it can be expressed as

$$a = \frac{F}{m} \quad (6.1)$$

$$\text{or} \quad F = ma \quad (6.2)$$

where a denotes acceleration, F denotes force and m denotes mass of the object. The direction of acceleration is the same as the direction of net force.

Threads of Curiosity

How much does a force of 1 N feel? If you hold a 100 g mass in your palm, the upward force your palm applies on the mass is around 1 N.

You know that the SI units of mass and acceleration are kg and m s^{-2} respectively. If m = 1 kg, a = 1 m s^{-2}, then using Eq. (6.2) we obtain

$$F = (1 \text{ kg}) \times (1 \text{ m s}^{-2}) = 1 \text{ kg m s}^{-2} = 1 \text{ N}$$

One newton of force is defined as the force that produces an acceleration of 1 m s^{-2} on an object of mass 1 kg.

You know that under the influence of gravitational force, an object falls towards the Earth. During this motion, the acceleration involved is called the **acceleration due to the gravitational force by the Earth** and is denoted by g. Its unit is the same as that of acceleration, m s^{-2}. Using Eq. (6.2), the gravitational force acting on an object of mass m is

$$F = mg \quad (6.3)$$

Note

The acceleration due to gravitational force by the Earth (g) does not depend on the mass of the object.

The value of acceleration due to gravitational force by the Earth is g = 9.8 m s^{-2}. It can be taken to be nearly constant near the surface of the Earth. For quick estimations, one can also take g = 10 m s^{-2}.

Threads of Curiosity

As per Eq. (6.1) in Activity 6.3, doubling the force on the cart should have doubled the acceleration you measured. But in reality, you may have found the increase to be little less than a factor of two. Similarly in Activity 6.4, when you doubled the mass of the cart, the acceleration should have been halved but you might have found a slightly different value. Apart from measurement errors, the friction between the cart's wheels and the surface can lead to such differences.

Ready to Go Beyond

The more complete form of Newton's second law is expressed in terms of momentum. The momentum of an object is defined as the product of its mass and velocity. The direction of the momentum is same as that of the velocity. Newton's second law states that the rate of change of momentum of an object is proportional to the net force and takes place in the direction in which the net force acts. Newton's second law expressed in this form is applicable to situations even where the mass of the object is not constant.

Fig. 6.18: Catching a cricket ball

Newton's second law of motion is considered to be a fundamental law of nature. Many events around us can be explained on the basis of Newton's second law of motion.

In a game of cricket, you might have noticed that while catching a fast-moving ball, the fielder gradually pulls their hands backwards with the moving ball just after catching it (Fig. 6.18). In doing so, the time duration is increased during which the high velocity of the ball reduces to zero. This reduces the magnitude of the acceleration of the ball as it slows down thus, requiring a smaller force to be applied by the fielder to stop the ball. Applying a smaller force to the moving ball also minimises injury to the fielder.

Bridging Science and Society

For a similar reason, airbags are provided in vehicles (Fig. 6.19). In the event of a collision and the vehicle coming to an abrupt halt, the airbag inflates quickly into a soft compressible cushion. Instead of directly hitting the hard steering wheel or dashboard, the passenger's head and chest push into the bag and the time over which the hitting occurs increases. Smaller acceleration means a reduced force exerted on the person, thereby lowering the risk of serious injuries, particularly when combined with the seat belt usage.

Fig. 6.19: Inflated airbag in a vehicle

Fig. 6.20: Cracking a coconut in one go

Have you ever attempted cracking a fresh coconut in one go? It is brought down at a very high velocity to hit a hard surface (Fig. 6.20). When the coconut hits the ground, it stops in a very short time. To change its velocity so quickly, the ground must exert a very large force on it. This large force breaks the shell.

Example 6.4: A weight lifter is holding a barbell with mass of 10 kg fixed on each side of the bar (Fig. 6.8). The mass of the bar itself is 10 kg. How much force is she applying to keep the barbell steady?

Answer: The total mass of the barbell is 30 kg. The gravitational force, due to the Earth, acting on the barbell in the downward direction is (using Eq. 6.3),

$F = mg = 30 \text{ kg} \times 9.8 \text{ m s}^{-2} = 294 \text{ N}$

To keep the barbell steady, the weightlifter has to apply an equal force in the opposite direction. So, she is applying 294 N in the upward direction.

Example 6.5: A student is trying to push a stationary block of 25 kg on a horizontal floor. The maximum force of friction opposing this motion is 50 N. Determine the displacement of the block in 2 seconds if Rahul pushes it with a constant force of (i) 50 N and (ii) 55 N in the forward direction.

Answer:

(i) The force applied by the student is equal to the opposing force of friction. Thus, the two forces are balanced and the net force acting on the block is zero. So, the block will remain stationary.

(ii) The net force on the block is 55 N – 50 N = 5 N.

The mass of the block is 25 kg. Using the Newton's second law of motion, the acceleration of the block is

$$a = \frac{F}{m} = \frac{5 \text{ N}}{25 \text{ kg}} = \frac{5 \text{ kg m s}^{-2}}{25 \text{ kg}} = 0.2 \text{ m s}^{-2}$$

Using the kinematic equation, the displacement of the block in 2 seconds is $s = ut + \frac{1}{2}at^2 = \left[0 \text{ m s}^{-1} \times 2 \text{ s}\right] + \left[\frac{1}{2} \times 0.2 \text{ m s}^{-2} \times (2 \text{ s})^2\right] = 0.4 \text{ m}$ in the forward direction.

Example 6.6: A sports car of mass 1500 kg is moving towards the east and its velocity-time graph is shown in Fig. 6.21. Calculate the force acting on the car during

(i) 0 s to 5 s

(ii) 5 s to 10 s

(iii) 10 s to 15 s

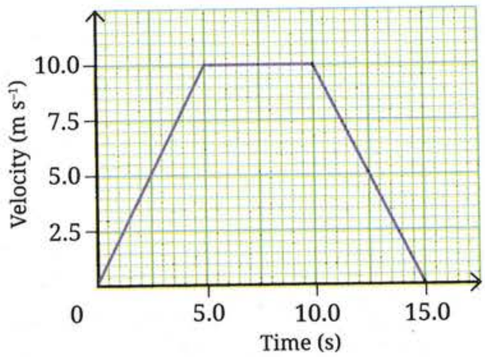


Fig. 6.21: Velocity-time graph for a sports car

Answer:

(i) During 0 s to 5 s:

As the velocity-time graph is a straight line inclined to the time axis, it indicates that the sports car is moving with a constant acceleration during this time interval with $u = 0\ \text{m s}^{-1}$, $v = 10\ \text{m s}^{-1}$ and $t = 5$ s.

Using the kinematic equation $v = u + at$, we can find the acceleration,

$10\ \text{m s}^{-1} = 0\ \text{m s}^{-1} + (a \times 5\ \text{s})$

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

Now, using the Newton's second law of the motion $F = ma$, we can find the force acting on the sports car as,

$F = 1500\ \text{kg} \times 2\ \text{m s}^{-2} = 3000\ \text{N}$ acting towards the east.

(ii) During 5 s to 10 s:

As the velocity-time graph is a straight line parallel to the time axis, it indicates that the sports car is moving with a constant velocity. Hence, no force is acting on the sports car.

(iii) During 10 s to 15 s:

As the velocity-time graph is a straight line inclined to the time axis, it indicates that the sports car is moving with a constant acceleration in this time interval with $u = 10\ \text{m s}^{-1}$, $v = 0\ \text{m s}^{-1}$ and $t = 5$ s. Using the kinematic equation $v = u + at$, we can find the acceleration,

$0\ \text{m s}^{-1} = 10\ \text{m s}^{-1} + (a \times 5\ \text{s})$

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

Now, using the Newton's second law of the motion $F = ma$, we can find the force acting on the sports car as,

$F = 1500\ \text{kg} \times (-2\ \text{m s}^{-2}) = -3000\ \text{N}$

The negative sign shows that the force is acting in a direction opposite to the direction of motion, that is towards the west.

Pause and Ponder

6. A toy car of mass 100 g is moving with a constant velocity of $0.5\ \text{m s}^{-1}$. What is the net force acting on the toy car?
7. Two children of different masses are sitting on identical swings. To impart identical initial acceleration, for which child would you require to apply a larger force? Explain why.
8. How are glass items packed for transportation using a bubble wrap or hay protected from damage?

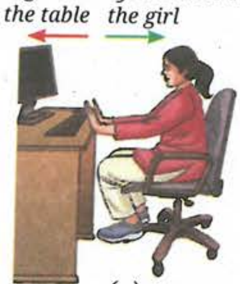
6.6 Newton's Third Law of Motion

Grade 8 Curiosity Chapter 5

We have described the behaviour of an object when a net force acts on it. But do you remember learning earlier that at least two objects must interact for a force to come into play?

Haven't you experienced that when you push a ball with your foot, you feel a force applied by the ball on your foot (Fig. 6.22)? It is then natural to ask how both the objects are affected in this process. Newton's third law addresses this issue.

Fig. 6.22: Kicking a ball



(a)

(b)

Fig. 6.23: Applying force on a table in the (a) forward direction, (b) reverse direction

Activity 6.5: Let us explore

1. Locate a chair with wheels and a large heavy table.
2. Sit on the chair with your legs raised above the floor. Now, using both your hands, push the table away from you, i.e., apply a force on the table in the forward direction as shown in Fig. 6.23a. What happens to you? Does the chair you are sitting upon move in the opposite direction?
3. Now, try to pull the table towards you, i.e., apply a force on the table in the direction opposite to that in step 2 (Fig. 6.23b). In which direction does your chair move now?

What conclusion can you draw from this activity? Each time, when you applied a force on the table, the table applied a force upon you in the opposite direction. You may have experienced this in various other situations.

If you are sitting on a bicycle and you want to move forward without pedalling, what do you do (Fig. 6.24)? You push the ground in the backward direction with your feet causing both you and the bicycle to move forward. This is because your feet apply a force on the ground and the ground applies a force on your feet in the opposite direction. This causes you to move forward along with the bicycle.

Fig. 6.24: Pushing the ground backwards

In fact, this is how you walk or run. Notice what you do while walking or running. You push the ground backwards with your feet (Fig. 6.25). The ground applies an opposite force on your feet to make you move forward. The force applied by the ground is in the form of friction. Thus, in this case friction helps you move rather than oppose you.

Fig. 6.25: Walking

Bridging Science and Society

While walking or running when you push the ground backwards with your foot, i.e., when your foot tries to slide backwards, the force of friction acts in the forward direction. Had there been no force of friction, your foot would have slipped backwards while attempting to push the ground and you would have fallen down. Grooves are made on the soles of footwear to increase the force of friction between the floor and soles. Similarly, treads on tyres of vehicles help increase the force of friction between the tyres and the road. You can now understand, why it is difficult to walk on wet polished floors or ice, or why it is risky to drive on roads covered with water or snow.

It was found experimentally that the magnitudes of such two forces are equal. Can you also observe this in some other way? You know how to measure the magnitude of the force using a spring balance.

Activity 6.6: Let us verify

1. Take two identical spring balances.
2. Place them in horizontal position on a table and connect them by their hooks as shown in Fig. 6.26. Fix the free end of one of the spring balances to an immovable object or hold it fixed by your hand.
3. Imagine that you are pulling the free end of the other spring balance with your other hand. **Predict** what will be the readings of their scales if the spring balances are stationary.
4. Now, carry out step 3. Repeat it multiple times by varying the magnitude of the force applied by you. Is your observation same as your prediction?

Fig. 6.26: Two spring balances connected together are pulled in opposite directions

The readings of the scales of two spring balances are the same every time. It indicates that the forces applied by them on each other in the opposite direction are equal in magnitude.

All these observations are summed up in the **Newton's third law of motion**, which can be stated as:

Whenever one object is exerting a force on a second object, the second object is simultaneously exerting an equal and opposite force on the first object.

Fig. 6.27: A person climbing a coconut tree

Note

The forces always occur in pairs but remember that these two forces act on two different objects.

Many daily life observations can be understood on the basis of the Newton's third law of motion. You might have seen a person climbing a coconut tree or palm tree (Fig. 6.27). The legs of the person climbing the vertically erect tree push down against the trunk. The friction between the trunk and the legs of the person pushes the person upwards by an equal force. Thus, it is harder to climb up the smooth tree trunks that have lesser friction.

Fig. 6.28: Rowing a canoe

Have you ever noticed how a boat or a canoe moves forward (Fig. 6.28)? When the canoeist pushes the water backwards with their paddle, the water pushes the paddle forward with an equal force. The two forces are equal in magnitude but act on different objects, the paddle and the water, so they do not cancel each other. The force on the paddle makes the paddle and the canoe move forward. When the canoeist pushes harder on the water, the forward force on the paddle is larger and the canoe's velocity increases.

Threads of Curiosity

Apart from how hard one paddles, there are several other factors (drag, water currents, mass of the canoe, style of rowing, etc.) which impact the speed of a canoe.

On television, you might have watched the rocket launches our country has done over the years. The launch of a rocket can also be explained on the basis of the Newton's third law of motion. To understand that let us first do a fun activity.

Activity 6.7: Let us understand

1. Collect a large balloon, a piece of drinking straw, adhesive tape, a long thread and two nails or hooks on two walls.
2. Inflate the balloon and tie its neck with a small piece of thread.
3. Stick the piece of straw with an adhesive tape on the surface of the balloon such that, one end of the straw points towards the neck of the balloon, as shown in Fig. 6.29.
4. Pass the thread through the straw and tie its two ends to the nails, keeping the thread taut (Fig. 6.29).
5. Remove the thread tied to the neck of the balloon and observe in which direction the straw and the balloon move.

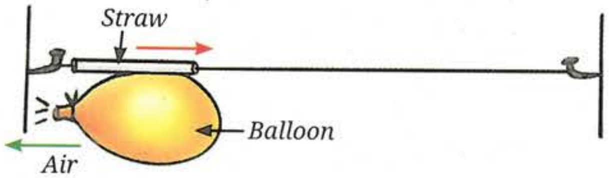


Fig. 6.29: Air rushing out of the balloon

The stretched material of the balloon applies a force on the air molecules inside to expel them as it shrinks in size. The air rushing out exerts an equal force on the balloon material in the opposite direction. This force causes the balloon to start moving in a direction opposite to the direction in which the air is rushing out.

A rocket moves in a similar manner (Fig. 6.30). Its engine produces gas and expels it in the downward direction, which in turn exerts an equal and opposite force on the rocket in the upward direction. This force on the rocket in the upward direction is larger than the weight of the rocket, so the net force is in the upward direction and the rocket lifts off.

What will happen if the engine of a rocket moving in the space, fires in the direction of its motion? The exhaust gases will exert a force in the direction opposite to the direction of motion of the rocket, thereby slowing it down. This process was used by the Vikram lander of Chandrayaan-3 to slow down and attain the necessary velocity for a soft landing near the south pole of the Moon.

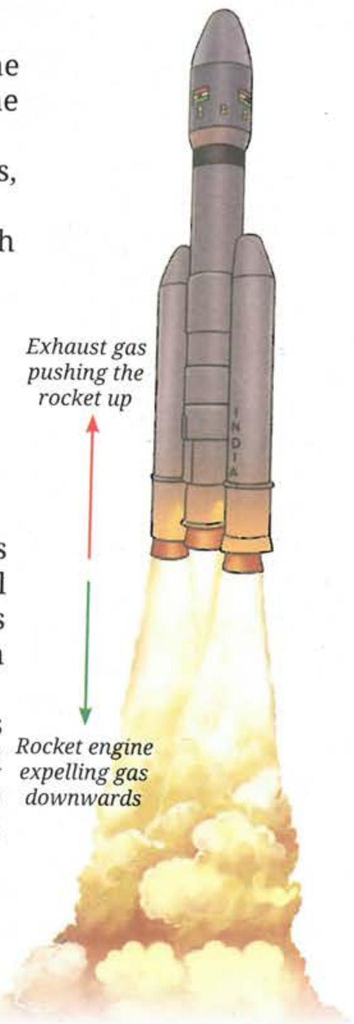


Fig. 6.30: Rocket launching

Note

The pair of equal and opposite forces (as per the Newton's third law of motion) acts on two different objects. Thus, they do not balance each other. On the other hand, if two equal and opposite forces act on the same object, they balance each other.

Pause and Ponder

9. Why does a fireperson sometimes struggle when holding the pipe issuing water?
10. Suppose a spacecraft is moving in a region of space where the gravitational force acting upon it is negligible. Suggest how can it change its velocity.

Grade 8 Curiosity Chapter 5

You have learnt about contact and non-contact forces earlier. Is Newton's third law applicable only for contact forces? Newton's third law applies to all types of forces, contact or non-contact, that we come across in everyday mechanical situations (Figs. 6.31, 6.32, 6.33).

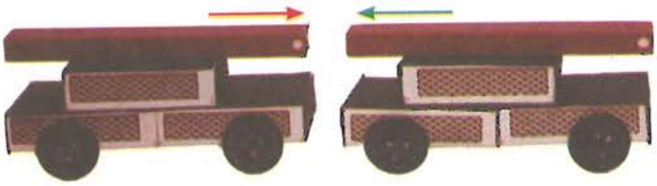


Fig. 6.31: Two bar magnets applying equal and opposite magnetic forces on each other

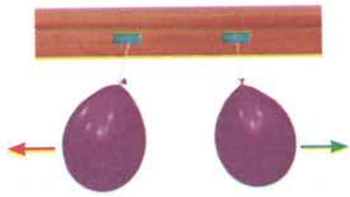


Fig. 6.32: Two similarly charged balloons applying equal and opposite electrostatic forces on each other

Fig. 6.33: The Earth and the fruit applying equal and opposite gravitational forces on each other

Example 6.7: As shown in Fig. 6.33, the Earth and the fruit apply equal and opposite gravitational forces on each other. Then why does the fruit move towards the Earth while the Earth doesn't seem to move towards the fruit?

Answer: Though the forces acting on both the Earth and the fruit are equal in magnitude; the mass of the Earth is so large (as compared to the fruit) that the acceleration of the Earth caused by the force is extremely small $\left(\text{as per } a = \frac{F}{m}\right)$. Thus, its effect on the Earth is too small to be noticed.

Example 6.8: When a 0.1 kg bullet is fired from a 5 kg gun with a force of 2 N, the gun recoils. What are the magnitudes of initial accelerations of the bullet and the gun?

Answer: From the Newton's third law of motion, the recoil force on the gun is also 2 N.

From the Newton's second law of motion, the initial magnitudes of acceleration of gun

$$= \frac{\text{force}}{\text{mass of gun}} = \frac{2\text{ N}}{5\text{ kg}} = 0.4\text{ m s}^{-2}$$

While the initial acceleration of bullet

$$= \frac{\text{force}}{\text{mass of bullet}} = \frac{2\text{ N}}{0.1\text{ kg}} = 20\text{ m s}^{-2}$$

Even though the pair of forces are equal in magnitude, the magnitudes of accelerations are not equal because their masses are different.

Note

Even though the forces acting on the two interacting objects are always equal in magnitude, they do not in general, produce equal acceleration. This is because the masses of the objects upon which they are acting may be different.

6.7 Forces Acting on a System of Objects

Until now, you studied the three laws of Newton as applied to a single object. These laws allowed you to predict the position and velocities of the object as forces act on it. But can we apply these laws to two or more objects connected together?

Consider two boxes of masses m_1 and m_2 placed on a frictionless horizontal surface and connected by a string (Fig. 6.34). A force F pulls Box 1 to the right. Box 1 applies a force on Box 2 via the string. By Newton's third law, Box 2 applies an equal and opposite force via the string on Box 1. We call this force tension T. On Box 1, the force F acts to the right, while the tension force T acts to the left. On Box 2, the tension force T acts on the right. How can we find the acceleration of each box?

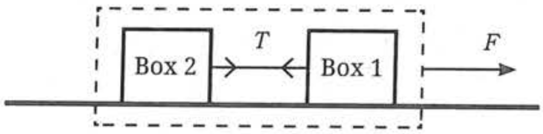


Fig. 6.34: A system of two boxes attached together by a string

One approach is to calculate the net force on each box separately and then use Newton's second law to find acceleration. A simpler way is to consider the two boxes and the string as a single **system**. In this approach, the forces within the system **(internal forces)** need not be considered and only forces that act from the outside **(external forces)** matter. In our case, the tension T acting on both the boxes is the internal force, while the force F is the external force. Thus, using Newton's second law (Eq. 6.1) the acceleration of the system is

$$a = \frac{F}{\text{mass of the system}} = \frac{F}{(m_1 + m_2)} \tag{6.4}$$

The system of two boxes accelerates just like a single object of mass $m_1 + m_2$.

If you had analysed the motion of the two boxes individually as you will learn to do in higher grades, the result would have been the same. Treating connected objects as a system often simplifies the analysis. This highlights the power of Newton's laws in studying even complicated systems of objects.

Next Level Up

Ready to Go Beyond

In addition to F, the external forces will be gravitational force ($m_1 g + m_2 g$) acting on the system downwards, which is balanced by the normal force ($N_1 + N_2$) acting on the system from the ground (Fig. 6.35).

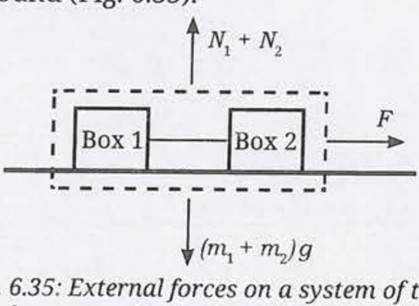


Fig. 6.35: External forces on a system of two boxes attached together by a string

Threads of Curiosity

While walking, your arms and legs move in a complex manner. Yet your overall motion can be studied by treating your body as a single object. Science often becomes simpler when we stop looking at parts and start looking at the whole.

At a Glance

- The force of friction acts on an object in the direction opposite to its direction of motion.
- Newton's first law of motion: An object at rest remains at rest and an object in motion continues to move with a constant velocity, unless a net force acts upon the object.
- Newton's second law of motion: When a net force acts on an object, the object accelerates in the direction of the net force. The magnitude of the acceleration is proportional to the magnitude of the net force and is inversely proportional to the mass of the object.
- Newton's third law of motion: Whenever one object is exerting a force on a second object, the second object is simultaneously exerting an equal and opposite force on the first object.

Revise, Reflect, Refine

1. Using a horizontal force *F*, a table is moved across the floor at a constant velocity. How much is the frictional force exerted by the floor on the table?
2. For a ball moving on a smooth frictionless surface, choose the appropriate option that will make the following statements physically correct.
   (i) If no net force is applied on the ball, the velocity of the ball will remain the same/increase/decrease.
   (ii) If a net force is applied on the ball in the direction of its motion, the magnitude of the velocity of the ball will remain the same/increase/decrease.
   (iii) If a net force is applied on the ball in a direction opposite to the direction of its motion, the magnitude of the velocity of the ball will remain the same/increase/decrease.
3. Two blocks P and Q on a smooth horizontal surface are shown in Fig. 6.36a and Fig. 6.36b. Two forces of magnitudes 4 N and 5 N are acting in opposite directions on block P, while block Q is moving with a constant velocity.

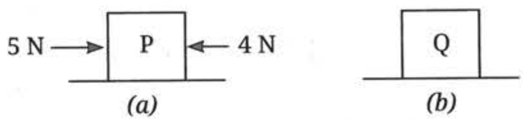
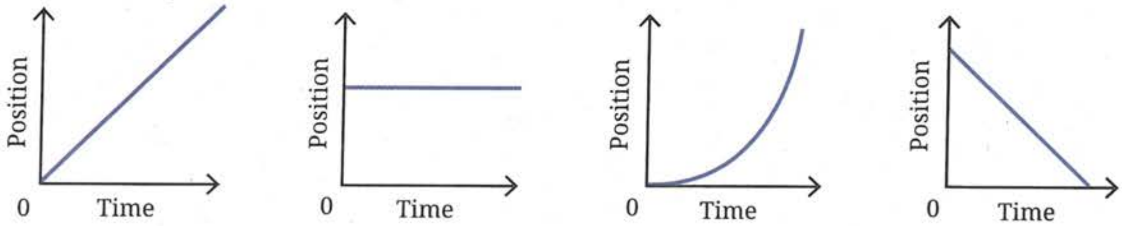


Fig. 6.36

Which of the following statement is correct?
   (i) P experiences a net force and Q does not experience a net force.
   (ii) P does not experience a net force and Q experiences a net force.
   (iii) Both P and Q experience a net force.
   (iv) Neither P nor Q experiences a net force.

4. While practising for the snake boat race (*Vallum kalli* in Kerala), 100 oarsmen are rowing a boat together. Out of these, 95 row backwards to propel the boat forward. But by mistake, 5 oarsmen row in the opposite direction. If each oarsman applies a horizontal force of 200 N, what is the net force on the snake boat? (Ignore drag forces, air friction, etc.)
5. When a net force acts on an object, we observe that the object accelerates:
   (i) opposite to the direction of force, with acceleration proportional to the force acting on the object.
   (ii) opposite to the direction of force, with acceleration proportional to the mass of the object.
   (iii) in the direction of force, with acceleration inversely proportional to the force acting on the object.
   (iv) in the direction of force, with acceleration proportional to the force acting on the object.
6. The position-time graph for four objects A, B, C and D moving along a straight line are given in Fig. 6.37. A net force acts on:
   (i) Object A
   (ii) Object B
   (iii) Object C
   (iv) Object D



Object A *Object B* *Object C* *Object D*

Fig. 6.37

7. A sailor jumps out from a small boat to the shore (Fig. 6.38). As the sailor jumps forward, will the boat move? If yes, in which direction and why.

Fig. 6.38: A sailor jumping forward

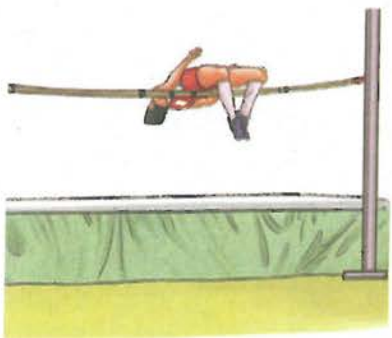


Fig. 6.39: A landing mat for a high jump event

8. During a high jump event, a landing mat or sand bed is placed for the athlete to fall upon (Fig. 6.39). Explain the reason behind it.

9. A hand cart loaded with vegetables collides with an identical but empty hand cart. During the collision:
   (i) the loaded cart exerts a force of larger magnitude on the empty cart.
   (ii) the empty cart exerts a force of larger magnitude on the loaded cart.
   (iii) neither cart exerts a force on the other.
   (iv) the loaded cart and the empty cart, both exert an equal magnitude of force on each other.
10. The acceleration-mass graph for the acceleration produced by a force on objects of different masses is plotted in Fig. 6.40. **Plot** the force-mass graph for this case.

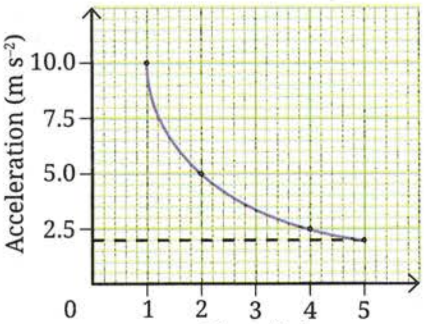


Fig. 6.40

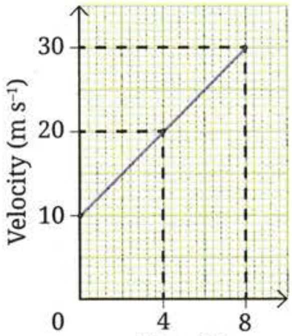


Fig. 6.41

11. The velocity-time graph of an object of mass 10 kg moving along a straight line is shown in Fig. 6.41. Calculate the force acting on the object by using the graph,.
12. A bullet of mass 50 g moving with a speed of 100 m s^{-1} enters a heavy stationary wooden block and stops after penetrating a distance of 50 cm. Estimate the stopping force acting on the bullet (assume that the bullet undergoes constant acceleration within the block).
13. An ace footballer converted a penalty shot by kicking the football with a speed of 108 km h^{-1}. The estimated force they imparted was 800 N. The mass of the football was 0.4 kg. Calculate the time of contact between their foot and the ball.
14. An object of mass 2 kg moving with a constant velocity of 10 m s^{-1} encounters a rough patch where the force of friction on the object is 7 N. At the same time, an additional constant force of 3 N opposing the motion is applied on the object. After entering the rough patch, how much distance does the object travel before coming to rest?
15. A tractor pulls a harrow (a ploughing tool) of mass m_1 with a net force F resulting in an acceleration of a_1. The same tractor pulls a trolley of mass m_2 with a force F producing an acceleration of a_2. If the tractor now pulls the trolley with the harrow placed on it (with the same force F), then obtain an expression for the resulting acceleration in terms of a_1 and a_2. Ignore friction.
16. When the pole of a bar magnet is brought close to a magnetic compass, the bar magnet and the compass needle (which is also a magnet) exert a magnetic force on each other. As per Newton's third law of motion, both the forces are equal in magnitude and opposite in direction. However, the compass needle moves, whereas the bar magnet does not move (Fig. 6.42). Explain why.

Fig. 6.42: A bar magnet and a magnetic compass

The Journey Beyond

- You know that the force of friction depends on the nature of the surfaces in contact. Does it also depend on how hard the surfaces press each other? Is the friction acting on an object that is about to move larger than the friction after motion begins? Is the friction which acts on a rolling object less than that on a sliding object? Find answers to these questions and **create** an infographic. Such observations help explain why the invention of the wheel was a major milestone in human history.
- Take two toy cars of equal mass and stick a bar magnet on top of each (Fig. 6.32). Fix a metre scale on a smooth surface. Place the cars near the midpoint of the metre scale with the like poles touching. Release the cars and record the time taken (using two stopwatches), and distance travelled by each before coming to a rest. Repeat the experiment after adding equal masses to both cars. Did the cars travel equal distances in opposite directions? Plot a graph of distance travelled versus mass. **Analyse** and discuss your findings.
- Wrap a rope once around a rough tree branch or post. Attach a heavy bucket to one end and try to hold it by the other end (Fig. 6.43). Now, add one more turn of the rope and repeat. You will find that each extra turn increases the 'grip' between the rope and the branch, increasing the friction and reducing the force required, making it much easier to hold the same load. The reduction in effort is much larger than you might expect from just adding one turn. This shows that friction does not increase in a simple linear way, small changes in contact can lead to large changes in force. In the same way, friction between a rope and a post allows large ships to be held safely at a pier.

Fig. 6.43

- It is often instructive to examine how scientific ideas develop over time. If you are interested, explore how Newton formulated the laws of motion by reading excerpts from his original work, the *Principia*. Both the original text and commentaries are available online.

Ready to Go Beyond

Newton's laws describe motion across an enormous range of scales, from everyday objects to planets and stars. They need modification only very close to massive objects, at extremely high speeds near the speed of light, and very small (atomic) scales.

The Quest Continues...

In the real world, friction is always present whenever surfaces are in contact. Scientists have been trying to find ways to reduce friction between surfaces by using lubricants, coatings or texturing of surfaces, streamlining shapes of objects, and by using magnetic levitation.

0906CH07

Chapter 7

Work, Energy, and Simple Machines

In earlier Chapters 4 and 6, you have learnt how forces change the motion of objects, and how kinematic equations and Newton's laws can be used to analyse motion. But when forces change with time or act in complicated ways, applying these laws directly can become difficult. Is there a simpler and more powerful way to understand such situations?

In this chapter, you will explore the ideas of work, energy and power, which often allow us to **analyse** motion and interactions more easily. You will also learn about simple machines, which help us perform tasks with less effort and more convenience. These form the building blocks of many everyday machines. Energy, which is the capacity to do work, lies at the heart of all these ideas and of almost every activity in our daily life (Fig. 7.1).

Think It Over

- What will be the magnitude of velocity of the child at the bottom of the blue slide?
- Will two children of different masses reach the bottom of the same slide with the same velocity?
- Which of the slides will result in the largest magnitude of velocity for the child at its bottom?

Food provides energy to walk — *Electricity provides energy to rotate a fan* — *Fuel provides energy to move a car*

Fig. 7.1: Energy required to carry out tasks comes from various sources

We often use the words work, energy and power in everyday conversations. As we learnt in Chapter 1, these terms have a precise meaning in science. Let us first understand how to **define** work.

7.1 Work Done by a Constant Force

Let us begin by doing some thinking based on our experience of lifting objects to a height.

Consider a wheat bag of mass 5 kg kept on the floor (Fig. 7.2a). Gravitational force mg acts downwards on the bag, where m is the mass of the bag and g is the acceleration due to gravity. To lift the bag slowly to a height of 1 m, you must apply an upward force equal to mg. The force applied by you acts upwards on the bag as the bag is displaced through a distance of 1 m in the direction of the force. In everyday language, you would say that you did some work.

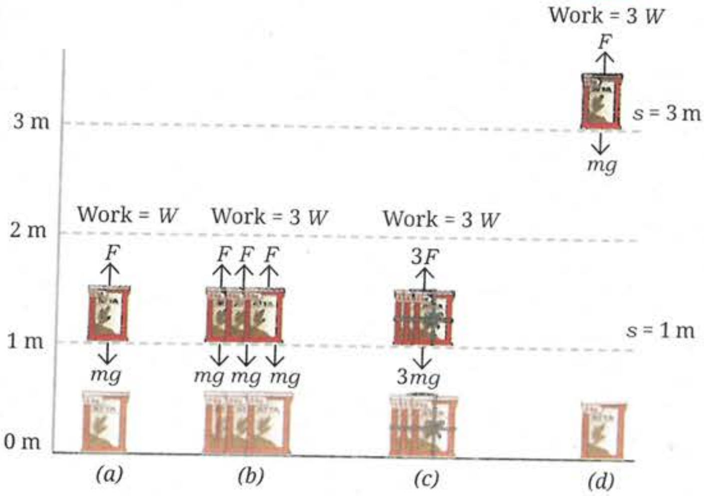


Fig. 7.2: Lifting bags to a height

If you lift 3 such bags one after the other to the same height (Fig. 7.2b), you would have done 3 times more work than to lift 1 bag. If the bag is lifted to the same height by a machine using some fuel, it will require 3 times more fuel to lift 3 bags.

Now, suppose you lift all the 3 bags together to the same height (Fig. 7.2c). You would need to apply a force 3 times larger than that required for a single bag. Since, you have done the same task as in Fig. 7.2b, the work done by you would be 3 times the work required to lift 1 bag. This shows that applying a larger force over the same distance allows you to proportionally do more work.

Next, consider lifting a single 5 kg bag of wheat but to a height of 3 m (Fig. 7.2d). You would have carried out 3 times more work as compared to the work required to lift the same bag by 1 m. Or if the same machine is used three times in succession to lift the bag by 1 m each time, it would require 3 times more fuel. Thus, applying the same force over a larger distance allows you to proportionally do more work.

Note

While describing the work done, it is important to specify the force (or agency) doing the work and the object on which the work is done.

The scientific definition of work done by a force is based on the above observations. The **work done by a constant force acting on an object** in bringing about a certain displacement can be defined as:

work done on an object by a constant force = force applied × displacement in the direction of the force (7.1)

In the example that we discussed, the displacement was in the vertical direction, however, Eq. (7.1) can be used even if the force and displacement, both are in a horizontal direction, or any other direction for that matter.

For example, consider an object upon which a constant force F is acting, and it undergoes a displacement s in the direction of force (Fig. 7.3). Then, the work done W by the force on the object is

$$W = F \times s \qquad (7.2)$$

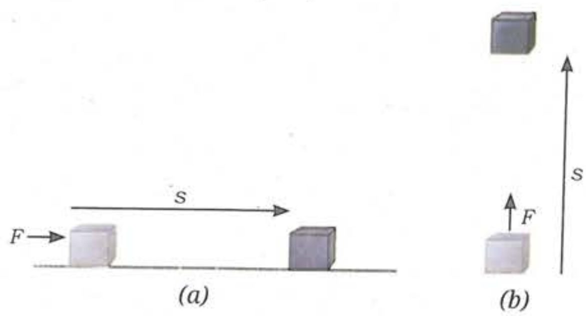


Fig. 7.3: Work done by a force while displacing an object in (a) horizontal direction, and (b) vertical direction

Ready to Go Beyond

Force and displacement have both magnitude and direction. Work, however, does not have a direction. It can be described using a number with a positive or a negative sign.

The **SI unit of work done** is **joule** which is represented by **J**. The SI unit of force is the newton (N) and the SI unit of displacement is the metre (m). Thus, using Eq. (7.2), 1 joule can be defined as

$$1\ J = 1\ N \times 1\ m$$

That is, 1 joule of work is done on an object when a constant force of 1 newton is applied to it and it is displaced by 1 metre in the direction of the force. Since $1\ N = 1\ kg\ m\ s^{-2}$, note that

$$1\ J = 1\ kg\ m\ s^{-2} \times 1\ m = 1\ kg\ m^2\ s^{-2}$$

In the graph shown in Fig. 7.4, the force on an object is plotted on the y-axis against the displacement in the direction of force on the x-axis. In this case, the work done on the object by the force is equal to the area of the shaded rectangle in the graph which is

$$10\ N \times 1\ m = 10\ J$$

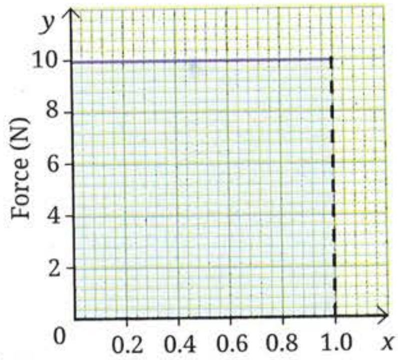


Fig. 7.4: Force-displacement graph

Even when the force is not constant, work done can still be calculated by finding the area under the force-displacement graph between the initial and the final positions.

7.1.1 When is work done equal to zero?

From the definition of work done (Eq. 7.2), you can see that if the force acting on an object is zero, i.e., $F = 0$, then no work is done on the object. The work done on an object is also zero if there is no displacement of the object, i.e., $s = 0$, regardless of the force being applied on it. For example, if you apply a force on an object, such as a rigid wall (Fig. 7.5), there is no displacement in the wall and you have done no work on the wall.


Fig. 7.5: Pushing a wall

This may seem odd because you feel tired. To apply a force, the muscles in your body repeatedly expand and contract, and use up the internal energy of your body. Thus, you may feel tired even though, in a scientific sense, you have not done any work on the object.

Ready to Go Beyond

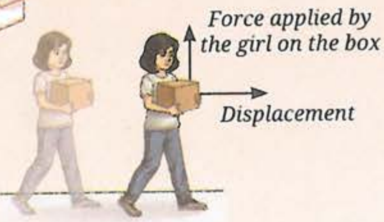


Fig. 7.6: Carrying a box

If a force acts in a direction perpendicular to the displacement of an object, the work done by that force is zero (Fig. 7.6) because there is no displacement in the direction of the force. For example, when a girl carries a box while walking, she applies an upward force to balance its weight, while the box moves horizontally. Since, the force and displacement are perpendicular to each other, no work is done by this force on the box. In higher grades, you will learn how to calculate the work done when force and displacement are at an angle to each other. Next Level Up

7.1.2 Positive and negative work done

The work done by a force on an object can either be positive or negative depending upon the relative directions of the force and the displacement. When the displacement is in the same direction as the applied force, the work done by the force on the object is said to be **positive**. For example, when you push a wheelchair, the force applied by you on the wheelchair and its displacement are in the same direction (Fig. 7.7a). Thus, you do positive work on the wheelchair.

When the displacement is in the direction opposite to that of the force, then the work done by the force on the object is **negative**. For example, while stopping a ball, the goalkeeper applies a force in a direction opposite to the direction of motion of the football (Fig. 7.7b), and hence, opposite to the displacement. As a result, the goalkeeper does negative work on the ball.

Note

The ball and the goalkeeper, both apply equal and opposite forces on each other. Both do work on each other. The ball does positive work on the goalkeeper, while goalkeeper does negative work on the ball.

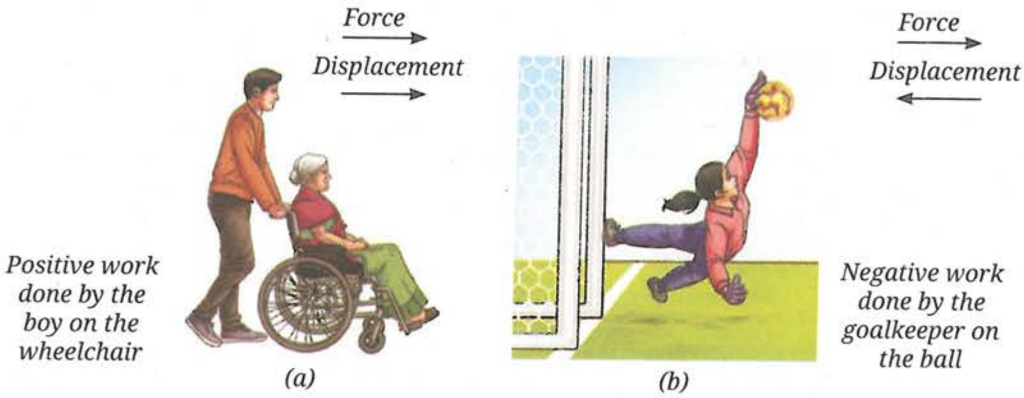


Fig. 7.7: Examples of (a) positive, and (b) negative work done on object

Example 7.1: While exercising, a girl lifts a dumbbell and slowly lowers it down. Identify when the girl does positive work on the dumbbell and when she does negative work on it.

Answer: The girl applies a force equal to the weight of dumbbell to lift it up. When she moves the dumbbell up, the force is in the direction of displacement, so she does positive work on it. When moving the dumbbell down, the force she applies to hold it is in a direction opposite to the displacement, so she does negative work on it.

Example 7.2: While saving a goal (Fig. 7.7b), a goalkeeper's hand moved back by 15 cm as she stopped a ball while applying a force of 200 N. How much work did the goalkeeper do on the ball in stopping it?

Answer: The goalkeeper applied a force opposite to the motion of the ball, so she did negative work on the ball. The displacement should be taken as negative because the ball moves in a direction opposite to the direction of the applied force.

Work done by the goalkeeper on the ball = force × displacement of ball in the direction of force

$= 200 \text{ N} \times (-0.15 \text{ m}) = -30 \text{ J}$

Pause and Ponder

1. In the previous chapter, a weightlifter is shown holding a barbell steady in her hands (Fig. 6.8). Is she doing any work on the barbell while holding it steady?
2. Is the work done by friction on the stack of coins that travels on a rough surface (Fig. 6.13c) — positive, negative or zero?

7.2 The Work-Energy Theorem

(a)

(b)

(c)

Fig. 7.8: (a) Throwing a cricket ball, (b) ball hitting the wickets, and (c) a flower pot falling from a height

We have seen that when a force is applied and an object is displaced, work is done on it. Does this cause the object to gain capacity to do further work?

Consider some everyday life examples. A fielder throws a cricket ball towards the wicket (Fig. 7.8a). The moving ball hits the wicket, making it fall (Fig. 7.8b). Similarly, a flowerpot raised to a height can damage an object below it if it falls (Fig. 7.8c). So, in each case, the ball or the pot has acquired a capacity to do some work. An object having the capacity to do work is said to possess **energy**. But how did the ball or the pot get their energy? The ball gained energy from the work done by the fielder in throwing it. The pot gained energy from the work done in raising it to a height.

When positive work is done on an object, it gains energy. Subsequently, the object can use that energy to apply a force on another object and cause it to move, thereby transferring energy. For example, when the ball hits the wickets, it transfers its energy to the wickets, making them move. Thus, work done on an object and its energy are closely related to each other.

Work done on an object appears as a change in its energy. The relation between the work done on an object and the change in its energy is called the **work-energy theorem**, which can be stated as

$$\text{work done on an object} = \text{change in its energy} \quad (7.3)$$

This theorem also holds for a system of objects or even when the forces applied on an object are not constant. This theorem can help us solve problems which we could not have done easily otherwise.

The **SI unit of energy** is the same as the SI unit of work, the **joule (J)**.

Ready to Go Beyond

Doing mechanical work is one way of transferring energy from one object to another. But that is not the only way! Energy can also be transferred as heat. When two objects at different temperatures come in contact, energy flows from the hotter one to the colder one. Energy can also move without direct contact. For example, the Sun's energy reaches the Earth through radiation. Energy is transferred in electric circuits, as well as via sound waves, and even in nuclear reactions that power the Sun.

Meet a Scientist

The SI unit of work and energy, joule, is named after the scientist, **James Prescott Joule**. He studied how mechanical energy and thermal energy are related, and can be converted from one to the other. This helped develop a unified way to understand energy.

Example 7.3: In a game of carrom, a player struck the shot shown in Fig. 7.9 to pocket the black coin. Identify who does work, and the changes in energy that occur at each collision.

Answer: The moving striker collides with the white coin, which in turn collides with the black coin. The moving striker applies force in the direction of displacement of the white coin. The striker, thus, does positive work on the white coin, increasing its energy. By Newton's third law, the white coin applies an opposite force and does negative work on the striker, decreasing its energy. Similarly, the white coin does positive work on the black coin increasing its energy, while the black coin does negative work on the white coin, decreasing its energy.

Fig. 7.9: A carrom shot

Pause and Ponder

3. When you pedal a bicycle on a flat road, your muscles supply energy. In what forms does this muscular energy appear as you ride?

7.3 Forms of Energy

As we have seen, energy is the capacity to do work. The examples that we have discussed till now correspond to the mechanical energy. But energy can exist in many other forms as shown in Fig. 7.10. It is possible to change energy from one form to another. For example, electrical energy is converted into light energy in a bulb, and into thermal energy of the water in an electric water heater. The chemical energy in the food we eat powers our muscles and gets converted into mechanical energy. Similarly, a ringing bell converts mechanical energy into sound energy.

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Among these, we will now look more closely at mechanical energy, since it is directly connected to the forces and motions you studied earlier.

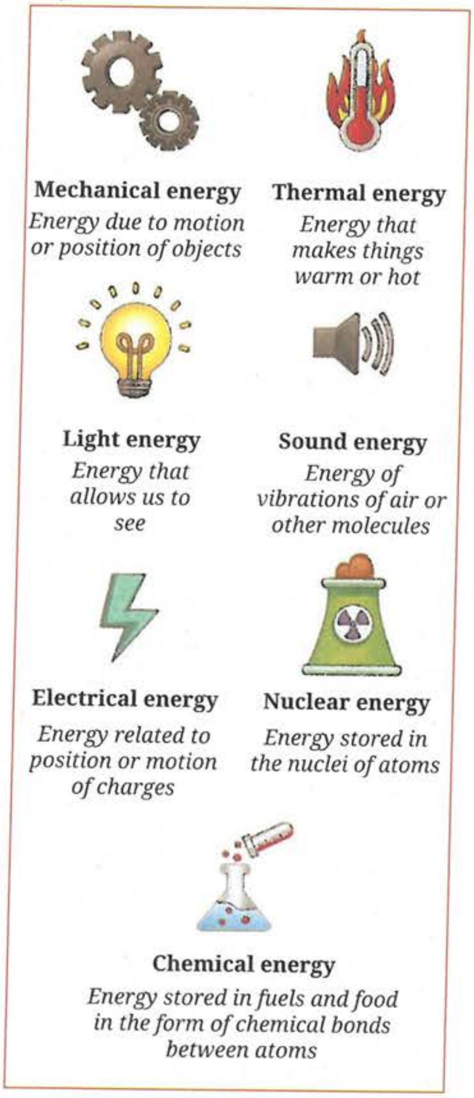


Fig. 7.10: Different forms of energy

7.4 Mechanical Energy

Mechanical energy is the energy that an object possesses due to its motion or position. Let us try to quantify mechanical energy by using the concept of work.

7.4.1 Kinetic energy

The energy possessed by an object due to its motion is called **kinetic energy**. All moving objects possess kinetic energy, such as a moving bicycle or a rolling ball.

How much is the energy possessed by an object by virtue of its motion? It is common to define an object that does not move to have zero kinetic energy. Consider an object that starts from rest and acquires a certain velocity under the influence of a force F (Fig. 7.11). Then by the work-energy theorem, the work done by the force will equal to the energy gained by the object, which is the kinetic energy of the object in this case.

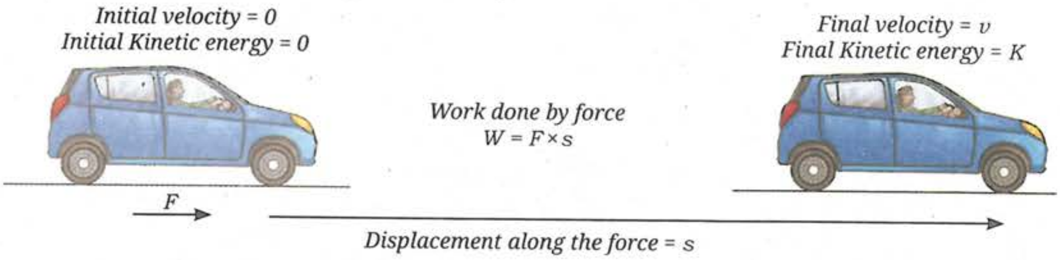


Fig. 7.11: Calculating change in kinetic energy using the work-energy theorem

Let us find a mathematical expression for the kinetic energy. For that, we will first find a general expression for work done by a force on an object of mass m, starting not from rest but from an initial velocity u. Let v be its final velocity as it undergoes a displacement s. To simplify the situation, let us assume that the force F acting on the object is constant. In that case, the acceleration a is also constant, and the kinematic equations can be used. We can then write

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

$$\text{or} \qquad s = \frac{(v^2 - u^2)}{(2a)} \tag{7.4}$$

From the definition of work (Eq. 7.2), the work done W by the force is

$$W = F \times s$$

Using Newton's second law, $F = ma$, we get

$$W = ma \times s$$

Substituting the value of s from Eq. (7.4), we obtain,

$$W = ma \times \frac{(v^2 - u^2)}{(2a)}$$

$$W = \frac{1}{2}m(v^2 - u^2) \tag{7.5}$$

From the work-energy theorem (Eq. 7.3), the work done by the force acting on the object translates into the change in the energy of the object. Thus, Eq. (7.5) represents the change in the energy of the object.

If the initial velocity of the object is $u = 0$, the change in the energy of the object is equal to its final kinetic energy. Thus, using Eq. (7.5), the kinetic energy of an object of mass m moving with a velocity v is

$$K = \frac{1}{2}mv^2 \tag{7.6}$$

The **SI unit of kinetic energy** is the **joule (J)**. The kinetic energy has no direction. When positive work is done on the object and its velocity increases, its kinetic energy also increases. If negative work is done on the object and its velocity decreases, its kinetic energy will also decrease. If no work is done by the force on the object ($W = 0$) and its velocity does not change, then its kinetic energy remains constant.

Example 7.4: If the velocity of a vehicle doubles in magnitude, what will its kinetic energy be compared to its original value?

Answer: Let the mass of the vehicle be m and its initial velocity be v. Its initial kinetic energy will be $\frac{1}{2}mv^2$. If the vehicle travels with a velocity of $2v$, its kinetic energy will be $\frac{1}{2}m(2v)^2 = 4 \times \frac{1}{2}mv^2$. The new value of the kinetic energy will be 4 times the previous value.

Example 7.5: In one of their fastest deliveries, an Indian cricketer bowled a cricket ball with an approximate mass of 0.2 kg at a velocity of about 154.8 km h^{-1}. **Calculate** the kinetic energy of the ball at the time of its delivery.

Answer: Mass of the cricket ball = 0.2 kg

Velocity of the ball = 154.8 km h^{-1} = 43 m s^{-1}

$$K = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.2 \text{ kg} \times (43 \text{ m s}^{-1})^2 = 184.9 \text{ J}$$

Example 7.6: A jet aircraft of mass 15000 kg lands on the deck of an aircraft carrier (Fig. 7.12). To stop the aircraft within the short length of the deck a hook on the aircraft's tail is caught in a wire stretched across the deck. The wire exerts an approximately constant backward force of 367500 N and stops the jet within 100 m. What was the velocity of the aircraft just before the wire caught the hook?

Answer: Let the aircraft approach with a velocity v

Initial kinetic energy of the aircraft $K = \frac{1}{2} \times 15000 \text{ kg} \times v^2$

Final kinetic energy of the aircraft $K = 0$ J

Change in the kinetic energy = $0 \text{ J} - \frac{1}{2} \times 15000 \text{ kg} \times v^2$

From Eq. (7.3),

Change in the kinetic energy = the work done by the wire.

The displacement of the aircraft and the force that the wire applies are in opposite directions. Therefore, the work done by the force applied by the wire will be negative.

Fig. 7.12: A jet aircraft landing on an aircraft carrier

Using Eq. (7.2), the work done by the wire = $F \times s$ = 367500 N × (– 100 m)

Substituting the values in Eq. (7.3), we obtain

$$-\frac{1}{2} \times 15000 \text{ kg} \times v^2 = -(367500 \text{ N} \times 100 \text{ m})$$

$$v^2 = \frac{36750 \times 2}{15} \text{ N m kg}^{-1} = 4900 \text{ kg m s}^{-2} \text{ m kg}^{-1} = 4900 \text{ m}^2 \text{ s}^{-2}$$

$v = 70 \text{ m s}^{-1} = 252 \text{ km h}^{-1}$ towards the aircraft carrier.

Pause and Ponder

4. Two objects A and B of mass m and 4 m have the same kinetic energy. What is the ratio of the magnitude of velocities of A and B?
5. Does the kinetic energy of an object which moves with constant velocity change with its position?

7.4.2 Potential energy

In Chapter 6, How Forces Affect Motion, you performed an activity (6.1) where you could move a stack of coins by releasing the stretched rubber band with which it was in contact. Have you ever played with a slingshot (*gulel*)? In this case, when you release the stretched elastic band, the object in contact with it shoots in the forward direction (Fig. 7.13a). You might have also watched an archery competition. The archer pulls on the string of the bow bending its arms in the process. When released, the bow comes back along with the string to its original position, and the arrow flies off the bow (Fig. 7.13b).

Fig. 7.13: (a) A slingshot

In these examples, you notice that when the stretched band or the bent bow is released, it applies a force on the object in contact with it. This sets the object in motion giving it kinetic energy. At the same time, the stretched band or bent bow comes back to its original shape. The stack of coins, ball and the arrow thus gain the kinetic energy they did not originally possess. This energy must have come from the stretched band and the bent bow, which have the capacity to do work due to their shape. The work done by the force which was applied to cause these deformations was stored in the band or the bow.

Fig. 7.13: (b) Shooting an arrow using a bow

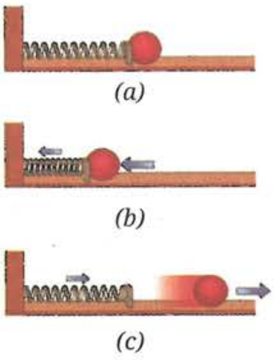


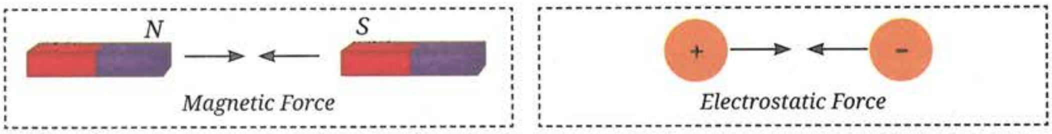
Fig. 7.14: Spring (a) in its original shape, (b) in compressed shape, and (c) moving back to its original shape

Similarly, when you apply a force and stretch or compress a spring (Fig. 7.14a), you do work on the spring to change or deform its shape. In turn, the spring stores energy or gains a capacity to do work while it is in a deformed state (Fig. 7.14b). While held in this state, the energy of the spring is due to its configuration or shape. When the spring is released, it comes back to its original shape. In the process, the spring transfers its stored energy to the kinetic energy of the object in contact (Fig. 7.14c).

Ready to Go Beyond

You need to apply an external force to overcome the internal forces in the spring to deform it. Once you remove this external force, the internal forces undo the deformation, and in the process, it can carry out work. Thus, internal forces allow energy to be stored in a deformed object.

Energy can be stored not only by deforming an object, but also by changing the arrangement of objects in a system. You have learnt that like poles of the magnets repel each other, while unlike poles attract each other. You must have experienced that separating unlike poles of two magnets from each other requires applying a force. When unlike poles are separated from each other and released (Fig. 7.15a), they move towards each other and gain kinetic energy. In fact, a small pea kept in between the two strong magnets, could even be crushed by their kinetic energy. This shows that the system of two magnets when separated from each other, can store energy due to their relative positions.



(a) (b)

Fig. 7.15: A system of two (a) magnets, and (b) electric charges

In the same way, a system of electric charges separated by a distance (Fig. 7.15b) also possesses the stored energy which can do work when released.

Now, consider a ball lying on the surface of the Earth. The ball and the Earth together form a system. You have learnt earlier that the Earth and ball attract each other. A force is required to do work against the gravitational force to lift the ball to some height. But once the ball is lifted to a height and the force is removed, the ball and the Earth rush towards each other, and attain kinetic energy in the process (Fig. 7.16). So, the system of ball and the Earth when separated from each other, store energy due to their relative positions.

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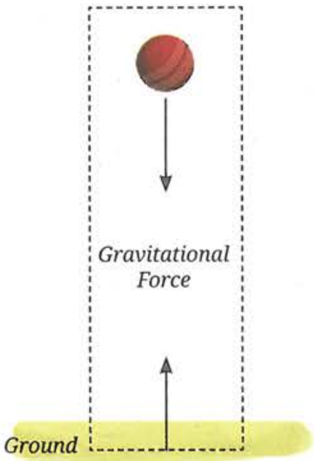

Fig. 7.16: Earth ball system

More generally, whenever a system of objects interacts through forces, such as gravitational, electric or magnetic forces, the system can store energy due to the relative positions of the objects.

The energy stored by an object as a result of its deformation or in a system of objects due to their relative positions is called the **potential energy.**

Gravitational Potential Energy

Among the various types of possible ways in which objects can have potential energy, we will look at the simplest case of the gravitational potential energy of Earth-ball system. The Earth is much more massive than the ball, and thus, it hardly moves towards the ball, as discussed in Example 6.8 of Chapter 6, How Forces Affect Motion. Therefore, the stored energy of the Earth-ball system is often, simply referred to as the gravitational potential energy of the ball. Let us carry out an activity to learn more about the potential energy of the ball due to the gravitational force between the ball and the Earth. Henceforth, in this chapter, potential energy usually refers to the gravitational potential energy.

Activity 7.1: Let us investigate

Fig. 7.17: Depressions created by a ball in sand dropped from different heights

1. Take a heavy ball and a large container filled with loose sand.
2. Raise the ball over the sand bed to a height of about 1 m and drop it (Fig. 7.17). Is a depression created in the sand? Why does the ball create a depression?
3. Now, raise the ball to the height of 2 m and release it at a slightly different position over the sand bed such that the depressions do not overlap. Repeat this step one more time. **Compare** the depths of the depressions. Is there any difference? In which case is the depression deepest and in which case the shallowest?

You find that the depression is deepest when the ball is dropped from the greatest height. Raising a ball to a greater height from the surface of the Earth requires more work. Thus, the ball possesses more energy at greater height. When the ball is released from a greater height, this energy creates a deeper depression. Thus, the greater the height of the ball above the Earth's surface, the greater is its potential energy.

We can arrive at an expression for the potential energy of an object by using the work-energy theorem. Consider an object of mass m lying on the ground (Fig. 7.18). We can define the potential energy to be zero in this configuration. To raise the object gradually from the surface of the Earth to a height h, we need to apply a force equal to the force mg between the Earth and the object. The work done W by this applied force on the object is

$$W = \text{force} \times \text{displacement}$$

$$W = mg \times h = mgh \qquad (7.7)$$

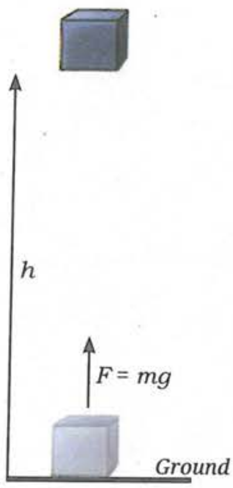

Fig. 7.18: Raising an object to a height

According to the work-energy theorem (Eq. 7.3), the work done on the object appears as a change in its potential energy. Thus, the potential energy U of the object at a height h is given by

$$U = mgh \qquad (7.8)$$

The **unit of potential energy** is the **joule (J)**, which is the same as the unit of work done or that of kinetic energy.

Ready to Go Beyond

Expression (Eq. 7.8) for the potential energy of an object at height h is valid only near the Earth's surface. Further away from the Earth's surface, the gravitational acceleration g decreases. You will learn about the gravitational potential energy of objects far from the Earth in higher grades. Next Level Up

Example 7.7: After taking a catch, a fielder threw the cricket ball of mass 200 g high up in the air about 10 m above the ground in celebration. How much potential energy does the ball have when the ball reaches its maximum height? Assume $g = 10\ \text{m s}^{-2}$.

Answer: Using Eq. (7.8), the potential energy of the ball will be equal to

$$mgh = 0.2\ \text{kg} \times 10\ \text{m s}^{-2} \times 10\ \text{m} = 20\ \text{J}$$

Pause and Ponder

6. Does the potential energy of an object near the surface of the Earth change if it moves with constant velocity in the horizontal direction? What if the object is gradually raised in the vertical direction?

Ready to Go Beyond

Work done on a system against its internal forces, such as gravitational, electric or magnetic forces, can result in a gain of the potential energy of the system. But this is not true for all internal forces. For example, work done against friction does not lead to a storage of energy. You will learn how to identify such forces in higher grades. Next Level Up

7.4.3 Conservation of mechanical energy

The sum of the kinetic energy and the potential energy of the object is called its **mechanical energy**. Let us find the mechanical energy of an object at different points as it falls freely due to the gravitational force.

Once again, consider an object with mass m which has been lifted to a Point A at height h and dropped (Fig. 7.19). Its initial velocity u is equal to zero.

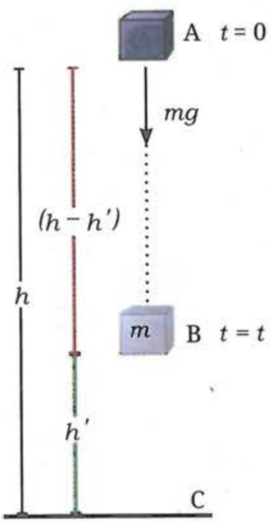

Fig. 7.19 An object falling freely due to gravity

Thus, at point A (using Eqs. 7.6 and 7.8):

potential energy of the object = mgh (7.9a)

kinetic energy of the object = 0 (7.9b)

mechanical energy = $0 + mgh = mgh$ (7.9c)

As the object falls due to the gravitational force (mg) for a time t till point B, its velocity increases to a value v. You can find the velocity v of the object and the height h' of point B from ground by using the kinematic equations (Use acceleration a to be equal to the acceleration due to gravity g).

$$v = u + gt = 0 + gt = gt$$

$$s = ut + \frac{1}{2}gt^2 \rightarrow h - h' = 0 + \frac{1}{2}gt^2 \rightarrow h' = h - \frac{1}{2}gt^2$$

Thus, at point B:

potential energy of the object $= mgh' = mgh - \frac{1}{2}mg^2t^2$ (7.10a)

kinetic energy of the object $= \frac{1}{2}mv^2 = \frac{1}{2}mg^2t^2$ (7.10b)

mechanical energy $= mgh - \frac{1}{2}mg^2t^2 + \frac{1}{2}mg^2t^2 = mgh$ (7.10c)

As the object falls down with time t, its potential energy decreases while its kinetic energy increases. Comparing Eq. (7.9) and Eq. (7.10), you find that at time t, the increase in the kinetic energy is equal to $\frac{1}{2}mg^2t^2$, which is also equal to the decrease in the potential energy, $\frac{1}{2}mg^2t^2$. This shows that the lost potential energy of the object is converted into kinetic energy during motion, while its mechanical energy remains constant and equal to mgh.

As an object moves due to the gravitational force, its mechanical energy remains the same, i.e., the mechanical energy of the object is conserved if no other external forces act on it. This is called the **conservation of mechanical energy**.

Let us conduct an activity to understand this. Do you remember experimenting with a simple pendulum earlier? Let us use that simple pendulum again to experiment further.

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Activity 7.2: Let us experiment

1. Set up a simple pendulum as you have learnt in Grade 7.
2. Paste a white sheet of paper on a wall behind the pendulum. Draw a horizontal line above the position of the bob when it is not oscillating (Fig. 7.20).
3. Take the bob to one side to a point P, which is at the level of the horizontal line and let it go. **Observe** it at the extreme points of the first couple of oscillations. Does the bob almost reach the level of the horizontal line?

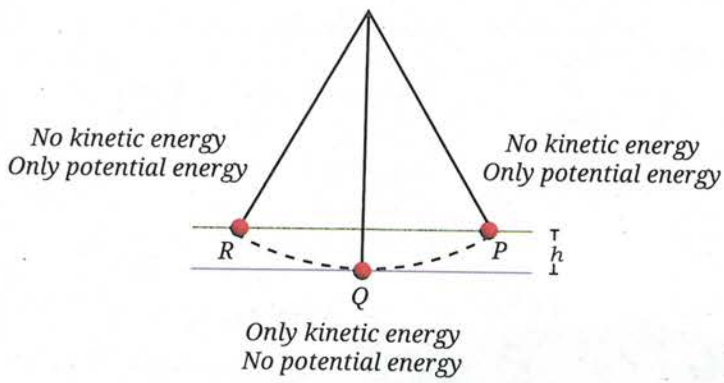


Fig. 7.20: A pendulum

At point P, the pendulum bob has the potential energy equal to mgh, where h is the height from the bottom-most point. At point Q, the potential energy is zero but the pendulum has kinetic energy. Finally at point R, on the other side of the pendulum where it stops, the kinetic energy is zero but the pendulum bob regains its potential energy. The pendulum bob reaches almost the same height it started with. This **demonstrates** that the mechanical energy of the bob remains constant. However, in real life, the pendulum slows down and eventually stops because of energy loss due to friction at the support and air resistance.

The conservation of mechanical energy can often be useful in solving several real-life problems.

Ready to Go Beyond

Mechanical energy is just one part of a bigger picture. In nature, energy can appear in many different forms. Scientists have discovered that the total energy of an object or system of objects which is not acted upon by any external forces, stays constant.

Threads of Curiosity

Solving problems directly through Newton's laws can become cumbersome in many cases. Conservation of mechanical energy may offer a simpler route. By keeping track of the total mechanical energy, we can often find the final speed or the position of an object without working through all the detailed steps of the intermediate motion of an object.

Example 7.8: What will be the magnitude of velocity of the child on reaching the bottom of the slide of height h?

Answer: Potential energy of the child at the top of the slide = mgh

Let the magnitude of velocity of the child on reaching the bottom of the slide be v. Then, the kinetic energy of the child at the bottom of the slide $= \frac{1}{2}mv^2$.

The potential energy of the child at the top of the slide gets converted entirely to the child's kinetic energy at the bottom of the slide (neglecting the effects of friction). Thus, equating the two, we obtain

$$\frac{1}{2}mv^2 = mgh$$

$$v = \sqrt{(2gh)}$$

As this velocity of the child at the bottom of the slide depends only upon the height h, the shape of the slide or the mass of the child should not matter.

Example 7.9: Escape ramps (Fig. 7.21) are inclined planes filled with sand or gravel that help stop trucks when their brakes fail on a highway. A truck of mass 10000 kg is moving at 72 km h^{-1} when its brakes fail. The driver steers it onto an escape ramp inclined at 30°, where the truck comes to a rest. If the sand exerts a force of 50000 N opposite to truck's motion, what is the minimum length of the ramp to be able to stop such a truck? Take g = 10 m s^{-2} (Hint: For a 30° incline, the truck rises 1 m vertically for every 2 m it travels along the ramp).

Fig. 7.21: Escape ramp

Answer: Velocity of the truck = 72 km h^{-1} = 20 m s^{-1}

Initial kinetic energy of the truck $= \frac{1}{2}mv^2 = \frac{1}{2} \times 10000\,\text{kg} \times \left(20\,\text{m s}^{-1}\right)^2$

$= 2000000$ J

Initial potential energy of truck = 0 J

Total initial energy of truck = Initial kinetic energy + Initial potential energy

= 2000000 J + 0 J = 2000000 J

Let us assume that the truck travels a distance d along the ramp. Then,

Height gained by the truck on ramp $= \frac{d}{2}$ (using hint given in the question)

Final kinetic energy of truck = 0 J

Final potential energy of truck $= mg \times \frac{d}{2} = 10000\,\text{kg} \times 10\,\text{m s}^{-2} \times \frac{d}{2} = 50000\,\text{N} \times d$

Total final energy = 0 J + 50000 N × d

Change in total energy of the truck = Final energy – Initial energy

= (50000 N × d) – 2000000 J

Work done by sand on truck = – 50000 N × d

Using work-energy theorem,

Work done by sand on truck = Change in total energy of the truck

– 50000 N × d = (50000 N × d) – 2000000 J

$$2000000\ \text{J} = (50000 + 50000)\ \text{N} \times d$$

$$d = \frac{2000000\ \text{J}}{100000\ \text{N}} = \frac{2000000\ \text{N m}}{100000\ \text{N}} = 20\ \text{m}$$

Thus, the minimum length of the ramp to be able to stop such a truck is 20 m.

Pause and Ponder

7. For the situation depicted in Fig. 7.19, calculate the mechanical energy of the ball just before it hits the ground and show that even at this position, it is *mgh*.
8. You may have seen an exhibit like that in Fig. 7.22 in a science park, where a ball is released from the highest point. Describe how the kinetic energy and potential energy change at points A, B and C. Why do subsequent points, such as C, D and E, usually have lower heights compared to the previous ones? Could it have anything to do with the energy lost due to friction?

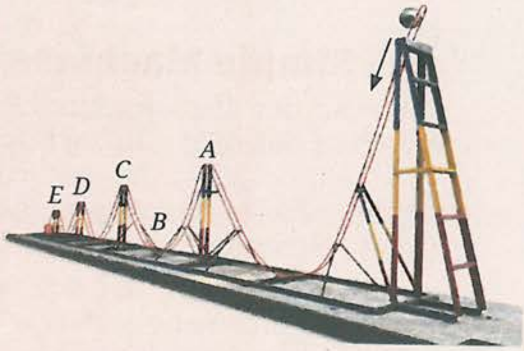


Fig. 7.22: Ball roller coaster in a science park

7.5 Power

Suppose you carry your bag up a flight of stairs to your classroom. Running up the stairs in one minute feels very different than walking up slowly in five minutes, even though the same work is done in both cases. This difference is described by a physical quantity called power.

Power is defined as the rate at which work is done. Mathematically, the average power P is the work done W, divided by the time taken t, i.e.,

$$P = \frac{W}{t} \tag{7.11}$$

To do more work in the same time interval, requires more power. To do the same amount of work but in a shorter time interval also requires more power. The **SI unit of power** is the **watt (W)**, where 1 watt is equal to 1 joule of work done per second, i.e., 1 W = 1 J s^{-1}.

Example 7.10: A weightlifter lifts a 75 kg mass by 2 m in 5 seconds. How much power would she require for this task?

Answer: The work done would be equal to $mgh = 75\ \text{kg} \times 10\ \text{m s}^{-2} \times 2\ \text{m}$

$$= 1500\ \text{J}$$

Thus, the power required will be $\frac{1500\ \text{J}}{5\ \text{s}} = 300\ \text{W}$

Example 7.11: A car of mass 1000 kg starts from rest and reaches a speed of 72 km h^{-1} in 10 seconds. Calculate the power of the engine required to achieve this start.

Answer: Final velocity, $v = 72\ \text{km h}^{-1} = \frac{72000\ \text{m}}{3600\ \text{s}} = 20\ \text{m s}^{-1}$

while initial velocity $u = 0\ \text{m s}^{-1}$

Threads of Curiosity

You may have heard about another unit called horsepower (hp) used to measure power, especially for car engines, or pumps used to lift water. One horsepower is equal to 746 W. In the early days, when engines were newly discovered, the powers of engines were compared to the power of actual horses which were used to drive carriages.

Work done by the engine in 10 s

$= \text{final kinetic energy} - \text{initial kinetic energy}$

$= \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

$= \frac{1}{2} \times 1000 \text{ kg} \times \left(20 \text{ m s}^{-1}\right)^2 - 0 \text{ J} = 200000 \text{ J}$

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{200000 \text{ J}}{10 \text{ s}} = 20000 \text{ W}$$

Meet a Scientist

The unit of power, watt is named in the honour of **James Watt**. He invented an efficient steam engine that could generate rotational motion and move wheels.

7.6 Simple Machines

In everyday life, we often need to do work against gravity or other forces, such as lifting or moving heavy objects. Although the total work required for a task cannot be reduced, it can be made easier by changing the magnitude or direction of the force that needs to be applied. The devices that help us do this are called **simple machines**.

In this section, we will study three simple machines — a pulley, an inclined plane and a lever — to understand how these make the task feel easier. The force we apply to a machine is called the **effort**, and force that needs to be overcome is called the **load**. To describe how a machine changes the magnitude of the applied force, we define **mechanical advantage** as the ratio of the load to the effort. It can be written as

$$\text{mechanical advantage} = \frac{\text{load}}{\text{effort}} \quad (7.12)$$

Fig. 7.23: Pulley

7.6.1 Pulley

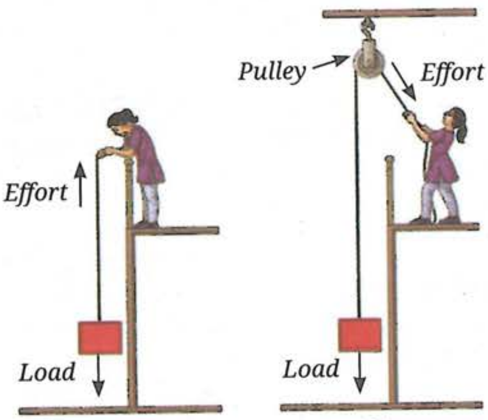


Fig. 7.24: Pulling up a load (a) directly, and (b) using a pulley

You may have seen a flag or a load being raised where a rope is pulled in the downward direction, while the flag or the load move in the upward direction. This is done with the help of a pulley fixed at the top. A **pulley** is a wheel with a groove that guides a rope (Fig. 7.23). A fixed pulley does not reduce the magnitude of the force required, it only changes its direction. It is easier for us to pull downward than to lift a load by applying an upward force directly (Figs. 7.24a and 7.24b). Thus, the pulley provides convenience by changing the direction of the effort. Since the effort and the load are equal in magnitude, the mechanical advantage of a fixed pulley is 1 (Eq. 7.12).

Ready to Go Beyond

Movable pulleys or a system of pulleys (Fig. 7.25) can have a mechanical advantage greater than 1 and can lift much heavier objects with much smaller effort. In a movable pulley system, the load is attached to the movable pulley. One end of the rope is fixed to a point, while the other end is free to apply effort. Pulleys are widely used in real life, such as in elevators and cranes given the convenience they provide us.

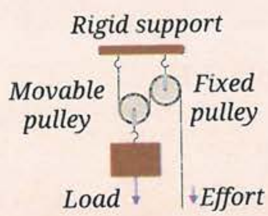


Fig. 7.25: A system of pulleys

7.6.2 Inclined plane

Suppose, you want to lift a heavy box onto a platform. Lifting it up vertically (Fig. 7.26a) requires an upward force F equal to its weight. But what if the box is too heavy for you to lift directly?

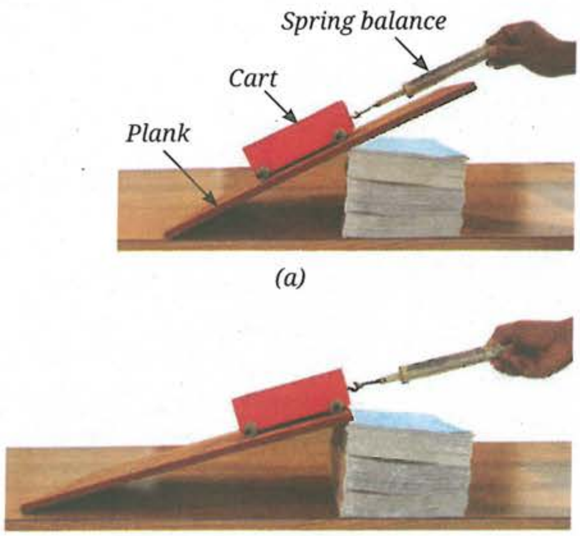
(a) (b)

Fig. 7.26: A box being (a) lifted vertically up, and (b) pushed up the ramp

You can place the box on a smooth inclined plank as shown in (Fig. 7.26b), and push the box up the plank to the platform. Does this method require a smaller force?

Activity 7.3: Let us experiment

1. Take a smooth plank (say a cardboard piece) about 1.5 m long, a toy car (or the cart that you used in Activity 6.3) and a spring balance. Attach the spring balance to the cart. Arrange an elevated surface, such as the top of a low stool or a pile of books, at about 0.5 m height from the floor.
2. First, lift the cart vertically, slowly and steadily, from the floor to the top of the pile of books or stool, and note the reading of the spring balance scale. This reading indicates that the force required to lift the cart vertically is equal to the weight of the cart.
3. Next, place the plank against the top of the pile of books or stool as shown in Fig. 7.27a. Pull the cart along the plank slowly and steadily. Is the reading of the spring balance (the force required) smaller than that of step 2?



(a)

(b)

Fig. 7.27: Measuring the force required to pull up a cart along an inclined plank of (a) smaller length, and (b) larger length

4. Now, reduce the angle between the plank and the base as shown in Fig. 7.27b, and repeat the step 3. Observe how the force required changes as the plank becomes less steep.

The force required to pull up the cart upto the height of the pile of books or stool decreases as the plank becomes less steep. However, you have to apply the force over a larger distance to bring it to the same height.

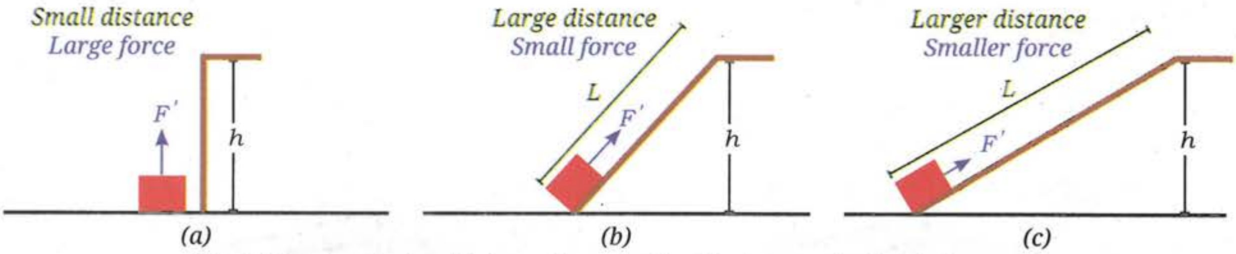


Fig. 7.28: A load being lifted up (a) vertically, (b) along an inclined plane, and (c) along an inclined plane of larger length

An **inclined plane** is a simple machine that helps move a heavy load to a higher (or lower) level. Let us now find its mechanical advantage.

Let the mass of the object be m. Then, the load is the weight mg of the object to be lifted. Let F' be the force required to raise the object to a height h (Fig. 7.28a). Then, F' is the effort. Let the length of the inclined plane be L (Fig. 7.28b).

Note

The work done, that is the product of force and displacement, is the same in all cases. If the force decreases, the displacement increases, thereby the work done remains constant.

If you move the object at constant speed up the inclined plane, then using Eq. (7.2),

$$\text{total work done by you on the object} = F' \times L$$

And using Eq. (7.8),

$$\text{potential energy gained by the object} = mgh$$

Thus, from the work-energy theorem (Eq. 7.3), we obtain (ignoring friction)

$$F' \times L = mgh$$

$$\text{Or, } \frac{mg}{F'} = \frac{L}{h}$$

Now, mg is the load and F' is the effort, so using Eq. (7.12), we obtain

$$\text{mechanical advantage} = \frac{\text{load}}{\text{effort}} = \frac{mg}{F'} = \frac{L}{h} \qquad (7.13)$$

Since L is larger than h, the force F' is less than mg and the mechanical advantage of inclined plane is greater than 1. By further increasing L, for example, by making the inclined plane longer with a shallower angle (Fig. 7.28c), we can further reduce the effort F' required to move the object.

Example 7.12: A person uses an inclined ramp to raise an object over a step 30 cm high. The ramp has a width of 40 cm. What is the mechanical advantage of the ramp that helps the person achieve the task?

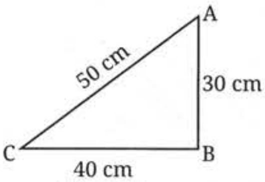


Fig. 7.29

Answer: As shown in Fig. 7.29, when the height AB is 30 cm and the width BC is 40 cm, the length AC of the ramp is 50 cm (right-angled triangle property).

$$\text{Using Eq. (7.13), mechanical advantage} = \frac{L}{h} = \frac{50 \text{ cm}}{30 \text{ cm}} = 1.67$$

Pause and Ponder

9. Explain why roads on hills are built to wind around in gentle slopes rather than going straight up (Fig. 4.26)?
10. To reach a higher floor, we find climbing an inclined ladder easier in comparison to climbing a vertical ladder (Fig. 7.30). Explain why.

Fig. 7.30: Climbing ladders

7.6.3 Lever

Activity 7.4: Let us investigate

1. Take a 30 cm long scale, a pencil, 2 – 3 erasers and a stapler (or a similar object).
2. Place the scale over the pencil such that the pencil is closer to one end of the scale as shown in Fig. 7.31. On the end of the scale closer to the pencil, place the stapler.
3. On the other end of the scale, place one eraser. Does the stapler lift up? If not, add one more eraser.

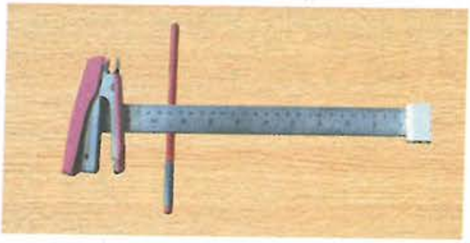


Fig. 7.31: Lifting a heavier object with lighter object

You may have noticed that a much heavier object (like a stapler) could be lifted by a much lighter eraser. This was made possible by using a scale as a simple machine called a lever. A **lever** is a rigid bar, such as your scale, that can rotate about a fixed point, such as the point of contact of the scale with the pencil.

In everyday life, levers are often used to lift heavy objects. A lever has three main parts (Fig. 7.32): (i) **Fulcrum**: a fixed point about which the lever rotates, (ii) **Load**: the force to be overcome, and (iii) **Effort**: the force applied. The distance of the load from the fulcrum is called the **load arm**, and the distance of the effort from the fulcrum is called the **effort arm**.

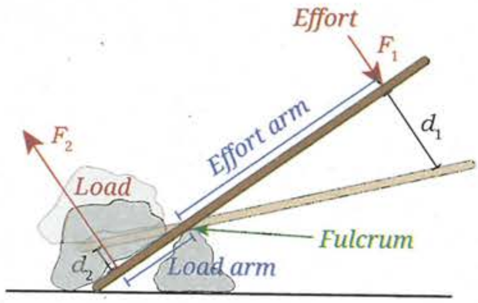


Fig. 7.32: A lever used to lift a heavy rock

By applying a small force at one end of the lever, a larger force can be applied on the object on the other end of the lever. How is this possible?

The end of the lever on which the smaller force (F_1) is applied, moves a larger distance (d_1), while the other end which applies a larger force (F_2) to lift a heavier object, moves a smaller distance (d_2). The work done on one end of the lever is transferred to the other end. Using Eq. (7.1)

$$F_1 \times d_1 = F_2 \times d_2 \quad (7.14)$$

Thus, by increasing the effort arm, the lever applies a larger force F_2 to the load compared to the applied effort F_1.

Note

A lever reduces the force required to perform a task but not the total work done.

Let us do an activity with a beam balance which is an example of a lever.

Activity 7.5: Let us experiment

1. Take a long scale (50 cm or larger), a piece of string, two paper cups (to act as pans), adhesive tape or a piece of thread and identical coins (to act as weights).
2. Tie the string tightly around the scale at its midpoint. This string will act as the fulcrum. Hang the scale from this string using a stand or hook, so that it can swing freely. This scale will now act as a beam (Fig. 7.33).
3. Fix paper cups to both ends of the beam using thread. These cups act as the pans of a balance. **Check** whether the beam is levelled. If it is tilted, adjust the hanging points of the pans until both sides balance equally.

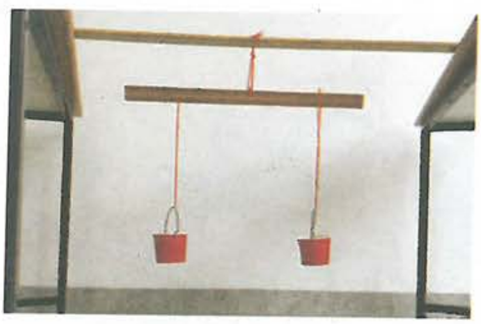


Fig. 7.33: Balancing cups hung on a scale

4. Place 1 coin in the left pan (call it effort) and 1 identical coin in the right pan (call it load). Observe that the beam stays horizontal.
5. Add one more coin to the right pan, so that it contains 2 coins. The beam tilts. Move the heavier pan closer to the centre of the beam to balance the beam. **Measure** its distance from the centre.
6. Repeat step 5 with 4 coins and then 8 coins in the right pan. Each time, note its distance from the centre that balances the beam.
7. **Record** all observations and measurements, and complete the Table 7.1 by adding more rows.

Table 7.1: Number of coins in the left pan and its distance from the fulcrum

Number of Coins in left pan, n_1 (Effort)	Distance of left pan from the fulcrum, L_1 (cm)	Number of coins in right pan, n_2 (Load)	Distance of right pan from the fulcrum, L_2 (cm)
1		1	
1		2	

By analysing the values recoded in Table 7.1, you can **conclude** that the beam balances when

$$n_1 \times L_1 = n_2 \times L_2$$

Or, effort × effort arm = load × load arm (7.15)

If the effort arm is increased, the effort required to move the same load is reduced. You can calculate the mechanical advantage of the lever by using Eq. (7.12). Thus,

$$\textbf{mechanical advantage} = \frac{\textbf{load}}{\textbf{effort}} = \frac{\textbf{effort arm}}{\textbf{load arm}} \quad (7.16)$$

Hence, by increasing the effort arm, the lever applies a larger force F_2 to the load than the effort F_1. The lever thus allows us to gain a mechanical advantage equal to the ratio of the distances, i.e., $\frac{L_1}{L_2}$.

With the use of a lever, the effort required is generally smaller but it has to move by a larger distance such that the total work done by the agency applying effort remains the same.

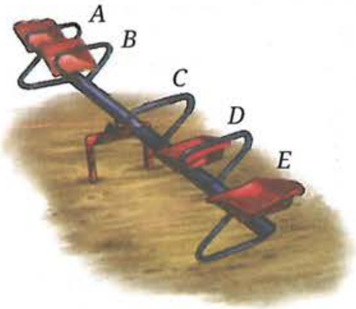


Fig. 7.34: A seesaw

Example 7.13: For a seesaw having four seats A, B, D, E and fulcrum at C (Fig. 7.34), AC = EC = 2 m and BC = DC = 1 m. On which seats should children of masses 15 kg and 30 kg sit to make the seesaw balanced?

Answer: Suppose the child of mass 15 kg sits on seat A and the other child sits at a distance L from the fulcrum. Using Eq. (7.15), we obtain

$15 \text{ kg} \times 2 \text{ m} = 30 \text{ kg} \times L$

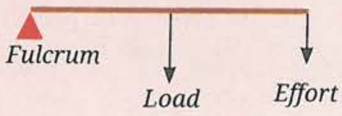
$L = 1 \text{ m}$

Thus, the other child should sit at seat D.

Ready to Go Beyond

Levers can be of three classes depending upon the relative positions of effort, fulcrum and load, as shown in Table 7.2.

Table 7.2: Classes of Levers

Levers		
Class I	**Class II**	**Class III**
Fulcrum in between	Load in between	Effort in between
		
		
Tongs, scissors, crowbar, pliers, balance scale, seesaw	Lemon squeezer, wheel barrow, bottle opener	Tongs, tweezers, broom, hammer, oar

Many machines used in daily life are made up of two or more simple machines. The next time you see a machine, try to identify the simple machines within them.

In all cases, the conservation of mechanical energy holds. The work we put in is equal to the useful work done on the load, ignoring friction. Machines do not create energy, they only help us use it more effectively.

Pause and Ponder

11. Why is it easier to open the lid of a can by using a spoon as shown in Fig. 7.35?
12. Why do you push an object closer to scissors (fulcrum) when you want to cut an object which is hard?
13. Throughout history, many designs of perpetual machines (using wheels, weights or magnets) have been proposed but none actually work. Why do all real machines eventually slow down and stop? Explain in terms of work and energy.

Fig. 7.35: Opening the lid by using a spoon

What If ...

it were possible to build a perpetual motion machine, which once started, could continue doing useful work forever, without any fuel or electricity?

Bridging Science and Society

In the Himalayan region, water flowing downhill converts its potential energy into kinetic energy. Traditionally, this energy was used in devices, such as the *gharat* or *panchakki* — a water mill used to grind grain (Fig. 7.36). These can still be found in hilly regions.

The water starts from the top with potential energy. This potential energy gets converted to kinetic energy as it comes down the pipe (A). The kinetic energy of the water drives the wheel (B) and sets it into rotational motion. The wheel is connected to the grinding stone at the top (C).

In modern times, the potential energy of the water stored in dams is similarly converted into kinetic energy to generate electricity.

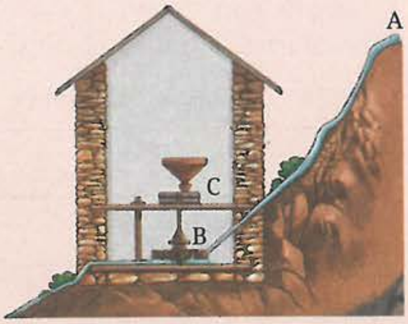


Fig. 7.36: A watermill (gharat or panchakki)

At a Glance

- Work is done by a force on an object, when the force displaces the object in the direction of the force.
- An object having capacity to do work is said to possess energy.
- Work-energy theorem: Work done on an object or a system is equal to the change in its energy.
- The energy possessed by an object due to its motion is called kinetic energy.
- The energy stored by an object as a result of its deformation or in a system of objects due to their relative positions is called potential energy.
- Power is defined as the rate at which work is done.
- Simple machines are devices that make work easier by changing the magnitude or direction of the force that needs to be applied, though they do not reduce total work.

Revise, Reflect, Refine

1. State whether True or False.
   (i) Work is said to be done when a force is applied, even if the object does not move.
   (ii) Lifting a bucket vertically upward results in positive work done on the bucket.
   (iii) The SI unit for both work and energy is joule (J).
   (iv) A motionless stretched rubber band has kinetic energy.
   (v) Energy can change from one form to another.

2. Fill in the blanks.
   (i) Work done = ______ × ______ (in the direction of force).
   (ii) 1 joule of work is done when a force of ______ newton displaces an object by 1 metre in the direction of the force.
   (iii) The expression for kinetic energy of a body of mass m and velocity v is ______.
   (iv) The potential energy of an object of mass m at a small height h from the Earth's surface is ______.
   (v) Power is defined as the ______ at which work is done.
3. When a ball thrown upwards reaches its highest point, tick which of the following statement(s) are correct?
   (i) The force acting on the ball is zero.
   (ii) The acceleration of the ball is zero.
   (iii) Its kinetic energy is zero.
   (iv) Its potential energy is maximum.
4. For each of the following situations, identify the energy transformation that takes place: (i) a truck moving uphill, (ii) unwinding of a watch spring, (iii) photosynthesis in green leaves, (iv) water flowing from a dam, (v) burning of a matchstick, (vi) explosion of a fire cracker, (vii) speaking into a microphone, (viii) a glowing electric bulb, and (ix) a solar panel.
5. A student is slowly lifted straight up in an elevator from the ground level to the top floor of a building. Later, the same student climbs the staircase, all the way to the top. Given that the height of the building is $h = 72.5$ m, acceleration due to gravity is $g = 10 \text{ m s}^{-2}$, and student's mass is $m = 50$ kg.
   (i) Find the gain in the potential energy if the student is lifted straight up to the top.
   (ii) Find the gain in the potential energy when the student climbs the stairs to the same top.
   (iii) What do you conclude about the dependence of the potential energy on the path taken?
6. A crane lifts a mass m to the 10th floor of a building in a certain time. It then raises the same mass to the 20th floor of the same building in double the time. How much more energy and power are required? Assume that the height of all floors is equal.
7. Which factors determine the energy required to raise a flag from the ground to the top of a tall flagpole using a pulley? Does raising the flag slowly or quickly change the amount of work done? If the speed at which the flag is raised is doubled, how does the power requirement change? Explain your answers.
8. A man of mass 60 kg rides a scooter of mass 100 kg. He accelerates the scooter to a velocity v. The next day, his son with a mass of 40 kg joins him as a passenger. If the scooter reaches the same speed on both days in the same time interval, what is the ratio of the fuel of the tank used on the two days? Assume that the energy transfer to the scooter happens entirely due to fuel, and no other losses occur due to air resistance and friction.

9. On a seesaw with sliding seats, a child is sitting on one side and an adult on the other side. The adult weighs twice that of the child. The seesaw however is balanced. **Draw** a figure which depicts this situation showing the distances from the fulcrum where the child and the adult are seated.

10. A ball of mass 2 kg is thrown up with a velocity of 20 m s^{-1}.
    (i) Identify the sign of the work done by gravity on the ball during its upward motion and its downward motion.
    (ii) If the ball reaches a height of 19.4 m, how much work was done by air resistance (assume $g = 10$ m s^{-2}).

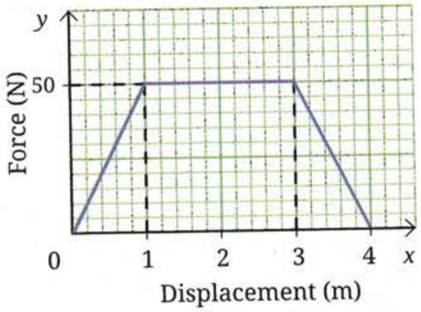


Fig. 7.37

11. A 10.0 kg block is moving on horizontal floor with negligible friction. As shown in the Fig. 7.37, a variable force is applied on the block in its direction of motion from its position at 0 m till 4 m. If the block had a kinetic energy of 180 J when it was at 0 m, find the block's speed (i) at 0 m, and (ii) at 4 m. Does the block have negative acceleration in any portion of its motion?

12. The gravitational attraction on the surface of the Moon (lunar surface) is about $\frac{1}{6}$th of that on the surface of the Earth. An astronaut can throw a ball up to a height of 8 m from the surface of the Earth. How far up will the ball thrown with the same upward velocity travel from the surface of the Moon?

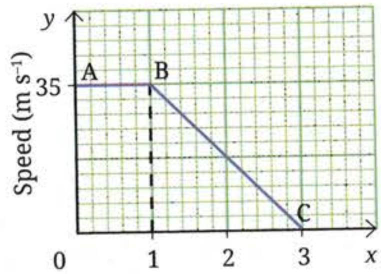


Fig. 7.38

13. A 1000 kg car is moving along a road at a constant speed. Suddenly, the driver notices some obstruction ahead and applies the brakes to come to a complete stop. The graphical representation of motion of the car starting from the instant the driver spots the traffic ahead is shown in Fig. 7.38.
    (i) Describe how the car moves between positions A and B.
    (ii) Calculate the kinetic energy of the car at A.
    (iii) State the work done by the brakes in bringing the car to a halt between B and C.
    (iv) What does the kinetic energy of the car transform into?

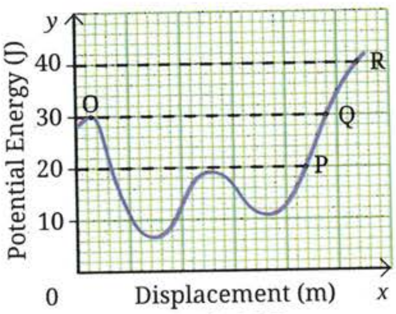


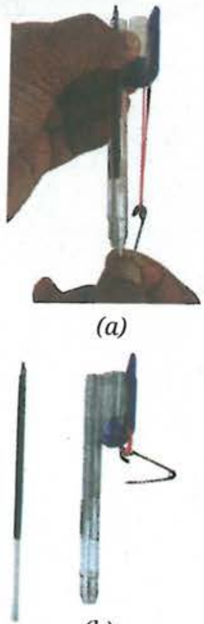
Fig.7.39

14. The potential energy-displacement graph of a 0.5 kg ball moving along a frictionless track is shown in Fig. 7.39. At O, the velocity of the ball is 0 m s^{-1} and potential energy is 30 J. Calculate the velocity of the ball at P, Q and R.

15. A coconut of mass 1.5 kg falls from the top of a coconut tree onto the wet sand on a beach. The height of the tree is 10 m. On impact, the coconut comes to rest by making a depression in the sand.
    (i) Calculate the velocity of the coconut just before it hits the sand.
    (ii) Assume that the average resistive force of sand is 3000 N and all of the coconut's energy is used to create the depression in the sand. Calculate the depth of the depression the coconut makes in the sand. Assume $g = 10$ m s^{-2}.

The Journey Beyond

- Remove both the ends from a pen so that the refill can slide freely through the barrel (Fig. 7.40). Fix the pen cap to the side of the barrel and attach a rubber band to the clip of the cap. Connect the free end of the rubber band to the refill using a safety pin. Stretch and release the rubber band. The refill shoots out, showing the conversion of elastic potential energy into kinetic energy. Repeat with different amounts of stretch, and observe how the distance travelled changes. Is there a relationship between the stretch and the distance travelled?



(a) *(b)*

Fig. 7.40

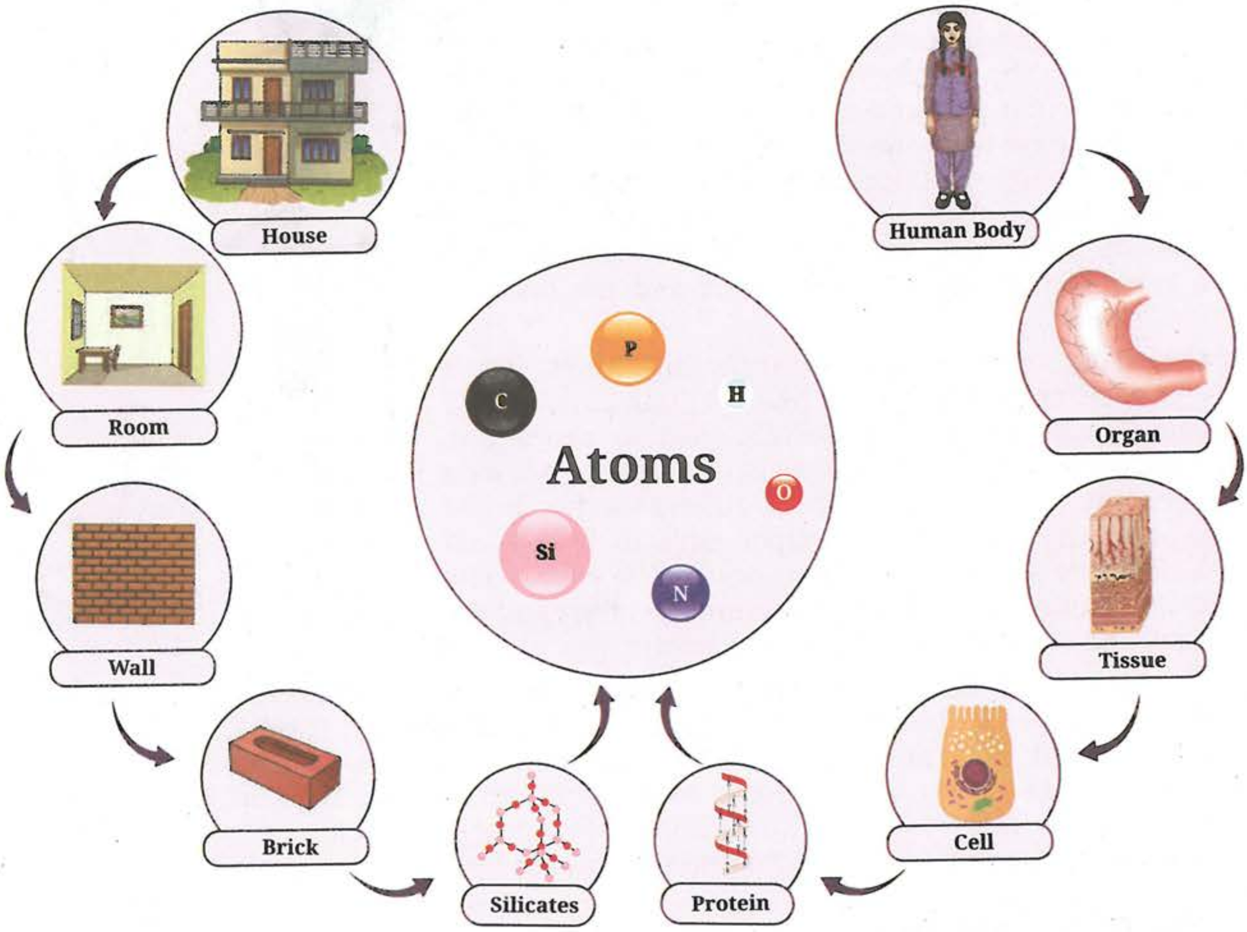
- **Construct** one or more simple machines, or a combination of them (lever, pulley and inclined plane) using easily available materials, such as cardboard, wooden strips or rulers, pencils or bolts (to act as a fulcrum), thread or rope, small pulleys (or two bottle caps stuck together), and paper cups to hold small weights. Be imaginative in your design. Use your model to lift or move a small load, measure the effort and the load, and calculate the mechanical advantage.
- Computer simulations can help in visualising physical quantities that are difficult to observe directly. The PhET simulations (https://phet.colorado.edu) provide interactive models, such as Energy Skate Park, Energy Forms and Changes, Pendulum Lab, and Masses and Springs. Use these to explore how different forms of energy change as parameters, such as mass, height and friction are varied.

The Quest Continues ...

For long, scientists have known that the Universe is expanding and surprisingly this expansion is accelerating. To explain this, scientists have proposed a new and rather mysterious form of energy called dark energy. There is no way to exchange dark energy with other forms of energy. Scientists try to study the effects of dark energy since it may govern the fate of the Universe, billions of years into the future.

Chapter 8

Journey Inside the Atom



Think It Over

- Are atoms the smallest indivisible particles?
- Why do electrons not fall into the nucleus even though they are attracted to protons in it?
- Why did scientists keep modifying atomic models?

Grade 8 Curiosity Chapter 7

Everything that you see or **observe**, or feel around is **matter**. You have learnt that matter consists of tiny particles called **atoms**. Take a closer look at the picture given above. What do you observe? Do you **notice** that both living beings, like us, and non-living things, like a house, are ultimately composed of atoms? These atoms are so tiny that they cannot be seen with the naked eye.

You may be wondering — Is an atom truly the smallest unit of matter, or can it be divided even further?

Scientists, too, have been exploring whether atoms are divisible. If so, what are their constituents and how are these arranged? Let us **examine** how the concept of atoms emerged and how it has been evolved since then.

8.1 Rediscovering the Roots of Atomic Theory

Let us embark on a journey that takes us back more than 2,000 years, to the intellectual landscapes of ancient India and ancient Greece. In these distant yet remarkably parallel civilisations, profound thinkers, such as Acharya Kanada in India, and Leucippus and Democritus in Greece, pondered over the same fundamental question that has continued to inspire human inquiry across centuries — What is everything made up of?

Acharya Kanada suggested that if matter (*dravya*) is divided repeatedly, you will reach a stage where you would encounter the smallest particles that can no longer be divided. He called these particles *parmanus*. His ideas are recorded in the Sanskrit text *Vaisesika Sutras*. A *parmanu* is infinitely small and cannot be perceived by the senses. Combinations of these forms dyads (groups of two *parmanus*) and triads (groups of three *parmanus*), and so on. It is out of these combinations that the whole of the material universe including the bodies of living beings is created. However, this description does not specify the proportions in which *parmanus* combine to form different substances.

The Greek philosophers Leucippus and Democritus also proposed a similar idea. They called these indivisible particles *atomos* (in Greek, *atomos* means indivisible).

You must remember that the concept of 'atom' originated as an imaginary idea rather than from experimental observations.

Many centuries later, in 1808, John Dalton proposed his atomic theory. It was based on scientific experiments of that time. He proposed that all matter is composed of indivisible particles called atoms. That is, the atoms are the fundamental building blocks of matter that cannot be broken down into smaller parts. Dalton's atomic theory was the first scientific description of how matter is made. It became the starting point for the current understanding of atomic structure.

You may be wondering how Dalton's idea evolved into a model for the structure of the atom.

Following Dalton's theory, scientists were curious to know the answers of the questions:

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

8.2 A Short Historical Journey Through Atomic Models

More than a hundred years ago, scientists tried to imagine what atoms might look like by proposing simple models. As new experiments were performed and new evidence came to light, these models were changed and improved. Although we now know that the early models were not fully correct, they are still important because they show how science moves forward — one step at a time, driven by curiosity, questioning, and experimentation.

Until the late 19th century, atoms were thought to be the smallest, indivisible units of matter. However, scientists discovered that certain elements emit invisible energy and particles called **radiation**,

Note

Atoms do not show any colour. The colours depicted in the diagrams are for illustrative purposes only.

a phenomenon known as **radioactivity**. This showed that atoms must be composed of smaller particles, proving that they were not indivisible as previously believed.

In 1897, J. J. Thomson studied the conduction of electric current through gases at a very low pressure. He used a glass tube with two electrodes and applied a high voltage. He observed rays moving from the cathode (negative electrode) to the anode (positive electrode) (Fig. 8.1). These were called cathode rays. By studying these cathode rays in electric and magnetic fields, he concluded that they are streams of negatively charged particles, with a much smaller mass than atoms. These particles, later called **electrons**, were emitted from atoms, indicating that atoms are composed of smaller subatomic components.

Meet a Scientist

J. J. Thomson's most significant discovery was that of the electron, the first subatomic particle to be identified and a part of every atom. He received the Nobel Prize in Physics in 1906 for his studies of the electrical conductivity of gases. This research led him to discover electrons. As the head of the famous Cavendish Laboratory in Cambridge, he guided and inspired many scientists, including Ernest Rutherford.

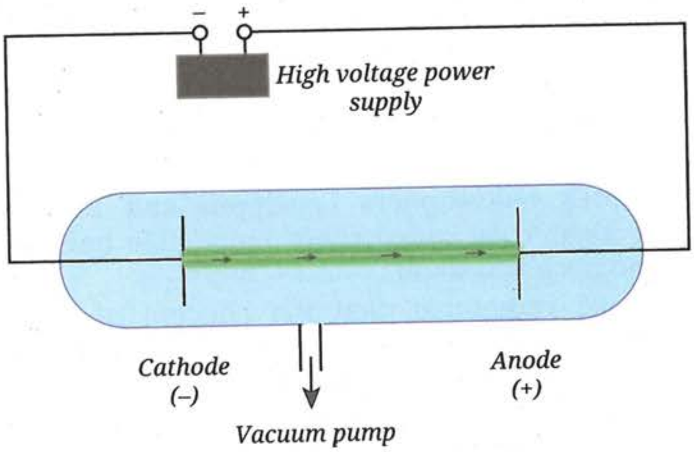


Fig. 8.1: A line diagram of cathode ray tube

It was found that the nature of cathode rays was independent of the material of the cathode and the gas filled in the cathode ray tube. It showed that electrons are a fundamental component of all atoms, present in every element. The charge of an electron (-1.602×10^{-19} C) is taken as –1 as a matter of convention and convenience.

8.2.1 Thomson's model of an atom

When J. J. Thomson discovered tiny negatively charged particles called electrons, he faced a puzzle — atoms are neutral, so where is the positive charge present? To solve this, Thomson proposed the atom to be a sphere of positive charge with electrons distributed throughout it (Fig. 8.2). This model was compared to a pudding with plums embedded in it, called the plum pudding model. A more familiar picture would be that of a watermelon (Fig. 8.3), where the red pulp represents the positively charged matter, and the seeds represent electrons distributed throughout the atom. This simple picture, though later replaced, was the first genuine attempt to describe how the atom's positive and negative charges stay balanced.

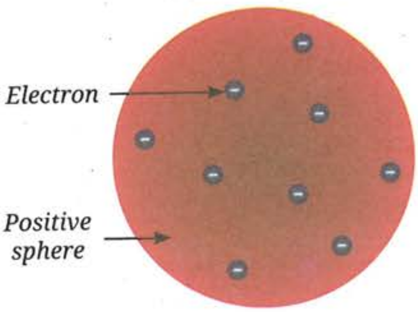


Fig. 8.2: Thomson's model of an atom

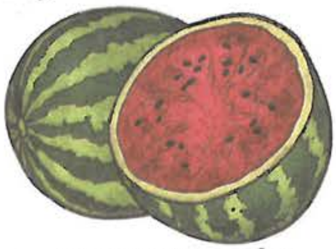


Fig. 8.3: Watermelon

Pause and Ponder

1. Suppose you made up your own 'atom', as Thomson described, using clay for the positive charge and small beads for the electrons spread through it. What will happen if:
   (i) the positive charge on the clay is lesser than the total negative charge of the beads?
   (ii) by mistake, the clay itself carries a bit of negative charge? Would your model still represent a neutral atom?
2. Could an orange or a lemon, which also contain seeds inside soft pulp, be a good comparison? In what ways does it match Thomson's idea and where does it fall short?
3. Why did Thomson conclude that electrons are present in all atoms?

8.2.2 Testing Thomson's model: The gold foil experiment

In 1911, Geiger and Marsden, working under Ernest Rutherford, tested Thomson's model of the atom through what became famous as the gold foil experiment. They aimed a narrow beam of alpha particles at an extremely thin sheet of gold foil. Alpha (symbol α) particles are tiny, positively charged particles emitted from certain radioactive elements. Later in this chapter, you will learn that an alpha particle is actually a nucleus of a helium atom containing two protons and two neutrons. According to Thomson's model, the positive charge in the atom was spread out evenly. So they expected the alpha particles to pass straight through the gold foil or be deflected only slightly. But to their surprise, while most particles passed through undeflected, some were sharply deflected (Fig. 8.4), and a few even bounced back. This deflection from the straight path is called **scattering**. Hence, the gold foil experiment is also called an **α-ray scattering experiment**.

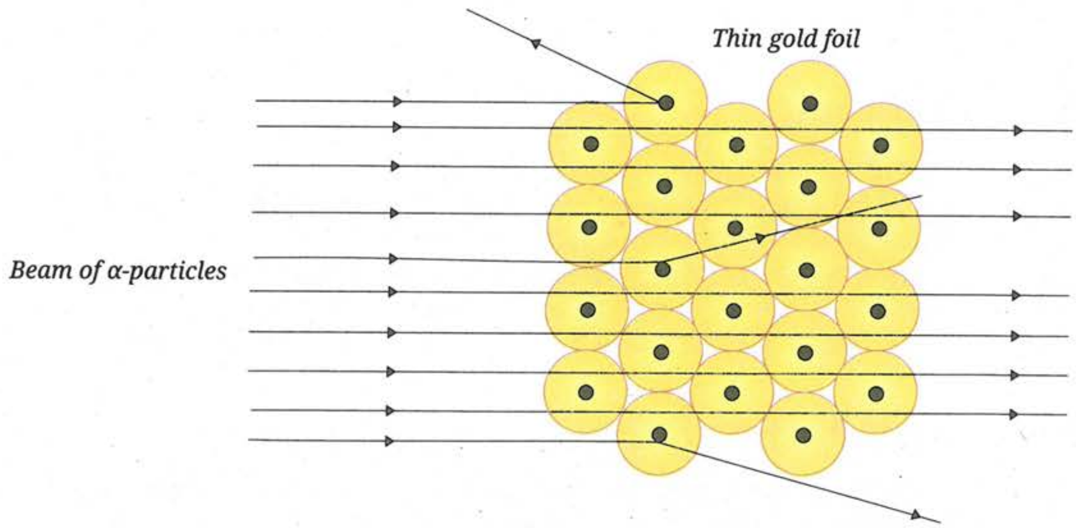


Fig. 8.4: Schematic view of the gold foil experiment

Thomson's model failed to explain the results of the gold foil experiment, particularly the deflection of some α-particles through large angles and that most of the α-particles passed undeflected.

A. Rutherford's model of an atom

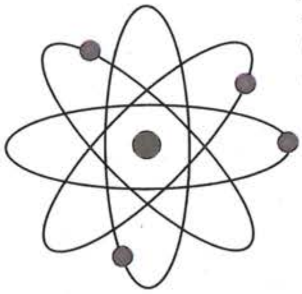


Fig. 8.5: Planetary model suggested by Rutherford

From the gold foil experiment, Rutherford concluded that the positive charge of an atom is not spread throughout but remains concentrated in an extremely small region called the **nucleus**. He proposed that:

- Most of an atom is empty space, as most α-particles passed through the gold foil without any deflection.
- The nucleus is dense, contains all the positive charge and most of the mass of an atom.
- The electrons revolve around the nucleus, somewhat like planets orbiting the Sun. Hence, this model is called the **planetary model of the atom** (Fig. 8.5).

Rutherford found that the nucleus is extremely small — about 10^5 (one lakh) times smaller than the atom. He calculated that the diameter of an atom is $\approx 10^{-10}$ m, and the diameter of the nucleus is $\approx 10^{-15}$ m. You can imagine that if an atom were of the size of a cricket ground (about 100 m across), the nucleus would be just a tiny black pepper grain (a few mm) at the centre!

Ready to Go Beyond

Can you calculate how many atoms would be needed to make a sheet of paper that is 0.1 mm thick, like the one in your textbook?

If the diameter of one atom is about 10^{-10} m, and the sheet is 0.1 mm (10^{-4} m) thick, number of atoms $\approx (10^{-4}\text{ m}) \div (10^{-10}\text{ m}) = 10^6$.

That is about one million atoms need to be stacked together! When these atoms come together, they form the solid materials we see and touch. What feels like a simple sheet is actually a vast assembly of tiny building blocks, all neatly arranged. It's amazing how the unseen atomic world shapes everything we see and use every day!

Think as a Scientist

Observe Fig. 8.4 of the gold foil experiment. **Predict** the observations you would expect if the gold foil in the experiment were made thicker. Also, draw a simple diagram to show the observations you expect.

Hint: Compare thin foil vs thick foil. How does the thickness affect the chances of hitting a nucleus?

Pause and Ponder

4. What do you think would happen if α-particles were replaced with negatively charged particles in Rutherford's gold foil experiment?
5. Rutherford found that a few α-particles bounced back sharply. How does this single surprising result completely rule out Thomson's 'plum pudding model' of the atom?
6. If you could ask Rutherford one question about his work, what would it be?

Rutherford's atomic model was better than Thomson's atomic model in explaining the results of the gold foil experiment. However, it had a limitation. It could not explain the stability of the atom.

B. Limitations of Rutherford's model

While the idea of a central nucleus was a major step forward, Rutherford's model could not explain why atoms are stable.

As you have learnt in Chapter 4, Describing Motion Around Us, a particle moving in a circular path is constantly changing direction, which means it is accelerating. If a negatively charged electron keeps accelerating around the nucleus, it should lose energy. Losing energy would make it spiral inward and eventually fall into the positively charged nucleus (Fig. 8.6). If that really happened, atoms would collapse and would not exist! But in reality, atoms are stable that is why matter around us stays intact. This meant that Rutherford's model was not completely correct, and a new explanation was needed to describe how electrons remain in motion without collapsing into the nucleus.

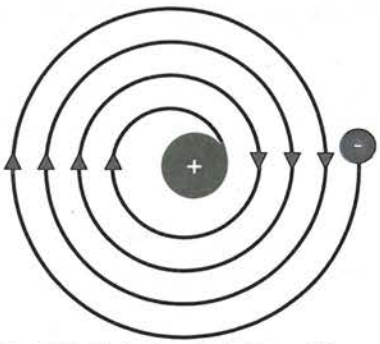


Fig. 8.6: Spiral path followed by a charged particle on losing energy

But before we come to that, you need to know about another subatomic particle, the proton, discovered and named by Rutherford.

Meet a Scientist

Born in New Zealand, **Ernest Rutherford** moved to Cambridge to work with J. J. Thomson and later became known as the Father of Nuclear Physics. He discovered the atomic nucleus and explained how some elements naturally break down, for which he won the 1908 Nobel Prize in Chemistry. In 1911, he proposed the nuclear model of the atom. His portrait now appears on New Zealand's $100 banknote.

C. Discovery of the proton

Rutherford showed that the nucleus carries positive charge which comes from the particles called **protons**. Protons are much heavier than electrons and possess a charge equal and opposite to that of electrons.

For an atom to be electrically neutral, the number of protons must be equal to the number of electrons. For example, a helium atom has 2 protons and 2 electrons, while a sodium atom has 11 protons and 11 electrons. Since the total positive charge equals the total negative charge, the helium or the sodium atoms are also electrically neutral. Similarly, all the atoms are electrically neutral.

Pause and Ponder

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

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

   Choose the correct option:

   (i) Both A and R are true, and R is the correct explanation of A.
   (ii) Both A and R are true, but R is not the correct explanation of A.
   (iii) A is true, but R is false.
   (iv) A is false, but R is true.

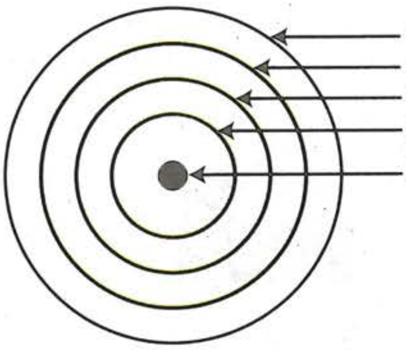


Fig. 8.7: Energy levels in an atom

8.2.3 Bohr's model of the atom

To explain why atoms are stable, Niels Bohr proposed a new model of the atom in 1913. According to Bohr:

- Electrons do not move randomly around the nucleus but follow fixed circular paths called **stationary states**, **orbits**, or **shells**. In each shell, an electron has a definite amount of energy, so these shells are also called **energy levels**.
- These shells are represented by the letters K, L, M, N, ... or by the numbers n = 1, 2, 3, 4, ... (Fig. 8.7).
- Electrons can revolve only in these allowed shells, and not in between them. While moving in a fixed shell, an electron does not lose energy.
- The first energy level K (n = 1) is the one closest to the nucleus (Fig. 8.7) and has the least energy.
- The energy of these levels increases as we move away from the nucleus. That is, the energy of an electron in the L-shell (n = 2) is more than that of an electron in the K-shell (n = 1). The farther away a shell is from the nucleus, the higher is its energy.
- An electron can move to another shell by absorbing or releasing a fixed amount of energy equal to the difference between the energies of the two levels.
- Each shell can hold only a certain number of electrons.

You may be wondering, how does Bohr's model explain stability? In Bohr's model, electrons also move in circular paths around the positively charged nucleus, as in Rutherford's model. But why don't they lose energy while doing so? Bohr addressed this by introducing the concept of stationary states as a postulate. In a stationary state, the energy of an electron remains constant, even though it is in motion around the nucleus. Bohr's model could explain many experimental observations and marked a major step in understanding the atomic structure.

Meet a Scientist

Niels Bohr was a professor of physics at Copenhagen University, Denmark. He was curious about how atoms exist because the old models could not explain why electrons stay around the nucleus without collapsing. His explanation of the atomic structure provided more clarity. Niels Bohr received the Nobel Prize in 1922, for his work on the structure of the atom.

Threads of Curiosity

Why are Bohr's shells called K, L, M, N... and not, A, B, C, D?

The naming came from early X-ray experiments by the physicist, Charles Barkla, who called the first observed X-ray line K. He didn't start naming from A to leave room for possible discovery of a series earlier than the K series, although none were ever found. Bohr adopted the same notation for atomic shells.

Later, even Bohr's model was found to have limitations, and yet another model, the quantum mechanical model, was proposed. You will learn about it in higher grades.

Next Level Up

8.3 What Components Contribute to the Mass of an Atom?

Rutherford's model showed that most of the mass of an atom is concentrated in its nucleus. Electrons that revolve around the nucleus are so light that their mass can be ignored.

However, something puzzling appeared early in the 20th century. For instance, a hydrogen atom has one proton, whereas a helium atom has two protons, yet the mass of a helium atom is about four times that of a hydrogen atom, not double. This led scientists to wonder whether besides protons, is there something else in the nucleus adding mass without affecting its charge?

8.3.1 Discovery of the Neutron

In 1932, this problem was solved by James Chadwick (a student of Ernest Rutherford). He discovered a new subatomic particle with a mass nearly equal to that of a proton but no electrical charge. This neutral particle was named as **neutron** and is usually represented by the symbol '***n***'. The neutrons are found in the nucleus of all atoms except hydrogen. Thus, the mass of an atom comes mainly from its protons and neutrons packed tightly in the nucleus. This also explains why atoms are heavier than the mass of their total number of protons. Table 8.1 shows the symbols and relative charges of subatomic particles.

Table 8.1: Symbols and relative charges of subatomic particles

S.No.	Subatomic particle	Symbol	Relative charge
1.	Electron	e^-	–1
2.	Proton	p^+	+1
3.	Neutron	n^0	0

Threads of Curiosity

Lighter atoms often have an equal number of protons and neutrons (like carbon with six each or oxygen with eight each). However, as atoms get heavier, their nuclei have many more neutrons than protons. Iron has 26 protons and 30 neutrons, and by the time we reach uranium, the nucleus has 92 protons and 146 neutrons.

You may wonder that since all the protons with like charges are squished together in a nucleus why do they not push each other away?

Think of it this way — every proton inside the nucleus repels every other proton because they all carry positive charge. Neutrons being neutral help reduce this repulsion by intervening and increasing the distance between protons, and also by strengthening the force, called the nuclear force, that binds all particles together. So, heavier atoms need many more neutrons to hold everything in the nucleus tightly bound.

What if ...

an atom had no empty space? How would this have affected the size of various objects?

Ready to Go Beyond

The discovery of the neutron opened a new era in atomic physics. Neutrons, being uncharged, can easily penetrate nuclei, leading to breakthroughs, such as the creation of artificial radioactive elements and the splitting of uranium atoms. This gave birth to the 'atomic age', allowing the development of both nuclear power and nuclear weapons.

Meet a Scientist

James Chadwick, working under Rutherford at the famous Cavendish Laboratory at the University of Cambridge, solved a key puzzle in 1932, when he discovered the neutron. This breakthrough explained atomic mass and earned him the Nobel Prize in Physics in 1935. The neutron immediately transformed research, enabling scientists to probe nuclear secrets, and sparked a chain of discoveries in understanding and harnessing atomic energy.

India's Scientific Contributions

The Bhabha Atomic Research Centre (BARC, Fig. 8.8), Mumbai, leads advanced neutron-scattering experiments using reactors, such as Dhruva. This has revealed key insights into materials like superconductors, battery electrodes, and drug molecules, helping develop better medicines, energy storage, and industrial alloys right here in India.

Fig. 8.8: Bhabha Atomic Research Centre

Research and explore more about Dhruva!

By 1869, scientists knew about 69 elements, most of which were found naturally on the Earth. Today, we know about 118 unique chemical elements. Some of these are artificially made, and the search for even more continues.

Now, let us explore how elements began to be represented for the sake of simplicity.

8.4 Symbols of Elements

John Dalton realised the need for a standard way to represent elements and compounds to make the study of chemistry easier. In 1803, he introduced the first **pictorial symbols** to represent the known elements. The Fig. 8.9 shows some of the symbols.

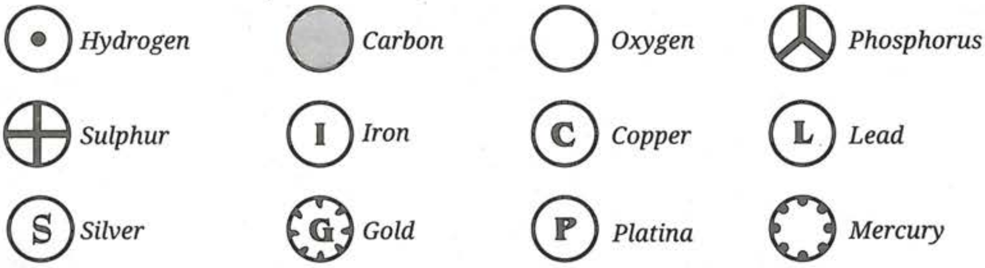


Fig. 8.9: Symbols of some elements given by Dalton

In 1813, Berzelius suggested that the symbols of elements should be derived from their Latin names. Thus, came alphabetic chemical symbols. Nowadays, the International Union of Pure and Applied Chemistry (IUPAC), an international scientific organisation, approves the names and symbols of elements. Some of the norms of writing these symbols are:

- Many symbols are the first letter or the first two letters of the name of the element.
- The first letter of a symbol is always written as a capital letter (uppercase) while the second letter (if there is one) is written as a small letter (lowercase). For example, hydrogen, H; aluminium, Al (not AL); cobalt, Co (not CO), etc.
- Symbols of some elements are formed from the first letter of the name and a letter other than the second letter in the name. For example, chlorine, Cl; zinc, Zn, etc.

- Symbols of some elements come from their Latin, Greek, or German names rather than English. For example, the symbol for iron is Fe (from Latin *ferrum*), for mercury is Hg (from Greek *hydrargyros*), and for tungsten is W (from German *wolfram*).
- Names and symbols of some commonly used elements are given in Table 8.2.

Table 8.2: Names of some common elements and their symbols

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

Scientists use these symbols instead of full names because they are internationally recognised and allow scientists worldwide to communicate clearly, regardless of language barriers.

Pause and Ponder

8. Imagine you are a scientist who has discovered a new element. Name this element after yourself and justify that the symbol you have chosen follows the IUPAC rules.
9. What problems could arise if every scientist used different symbols for the same element?

8.5 Atomic Number

You have learnt that the atoms of an element are all alike but different from the atoms of other elements. They differ in the number of electrons and protons in them. The number of protons in the nucleus of an atom of an element is known as its **atomic number**. It is designated by the symbol ***Z***, this number determines the identity of an element and its chemical behaviour.

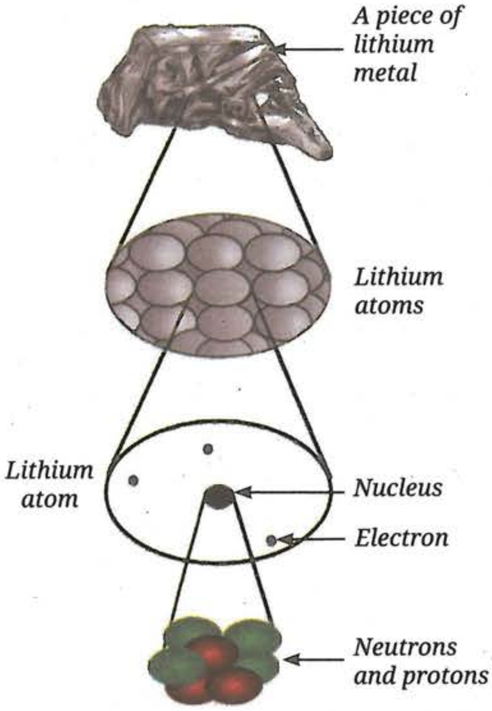


Fig. 8.10: Neutrons and protons in the nucleus

Since the atom as a whole is neutral, the number of protons in it equals the number of electrons orbiting the nucleus. For example, hydrogen has one proton and one electron, so its atomic number is 1. Helium, with atomic number 2, has 2 protons and 2 electrons.

Can you now say that elements with different atomic numbers are distinct from each other, and the atomic number uniquely identifies an element? Observe Fig. 8.10. How many neutrons and protons are present in a lithium atom, and what is its atomic number?

8.6 Mass Number

As stated earlier, helium has two protons, but its mass is about four times that of a proton. The total number of protons and neutrons present in the nucleus of an atom is called its **mass number**, and is denoted by ***A***. The protons and neutrons present in the nucleus are called **nucleons**.

Mass number = Number of protons + Number of neutrons

Since, the mass of a neutron is roughly equal to that of a proton, the mass of a helium atom can be accounted by two protons and two neutrons. A few examples are given in Table 8.3.

Table 8.3: Mass number of different elements

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

The electron, in comparison, has almost negligible mass, and hence, can be ignored in calculations.

In the standard notation for an atom, the symbol, the atomic number (Z) and mass number (A) of the element are written as —

$$^{\text{Mass Number}}_{\text{Atomic Number}}\boxed{\text{Symbol of element}}$$

For example, the symbol for carbon is C, its atomic number is 6, and its mass number is 12. In notation, it would be written as —

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

So far, you know that protons and neutrons are located in the nucleus of an atom, while electrons move around the nucleus. Now, let us explore how electrons are arranged around the nucleus.

Pause and Ponder

10. An atom with an atomic number of 26 has 56 nucleons. Find out its number of electrons, protons and neutrons.
11. The nucleus of an atom contains 20 protons. If its mass number is 41, find the number of neutrons in it.
12. An atom has 18 neutrons and an atomic number of 17. What is its mass number?
13. An atom ^{23}A has 11 electrons. Find the number of neutrons in it.

8.7 How Are Electrons Distributed in Different Energy Levels?

Bohr and Bury suggested the following rules:

- The maximum number of electrons present in a shell is given by the formula $2n^2$, where 'n' is the number of the shell (Fig. 8.7). Hence, K-shell (n = 1) $2\times1^2 = 2$, can accommodate 2 electrons, L-shell (n = 2) $2\times2^2 = 8$ electrons, and M-shell (n = 3) $2\times3^2 = 18$ electrons.
- The maximum number of electrons that can be accommodated in the outermost shell is 8 (the first shell can accommodate a maximum of two electrons).
- Electrons are filled in these shells in a stepwise manner, starting from the one closest to the nucleus and moving outward, i.e., in the order K, L, M, N, ... The L-shell will be filled only after the K-shell is complete, and so on.

To understand the placement of electrons in atoms, let us begin with hydrogen (atomic number 1). The only electron in it has to be in the K-shell. The electron distribution for hydrogen (H) is depicted in Fig. 8.11. Helium contains two protons in its nucleus and two electrons. In which way will the two electrons be arranged in its atomic shell?

8.7.1 Building up atoms

Let us create two-dimensional (2-D) atomic structures for various elements by adding one electron to the appropriate energy level each time atomic number is increased by 1. The distribution of electrons among various shells is known as the **electronic configuration** of the atom (Fig. 8.11). Table 8.4 lists the symbols, atomic numbers, number of protons, number of neutrons, number of electrons, and the electron distribution in the shells of the first eighteen elements.

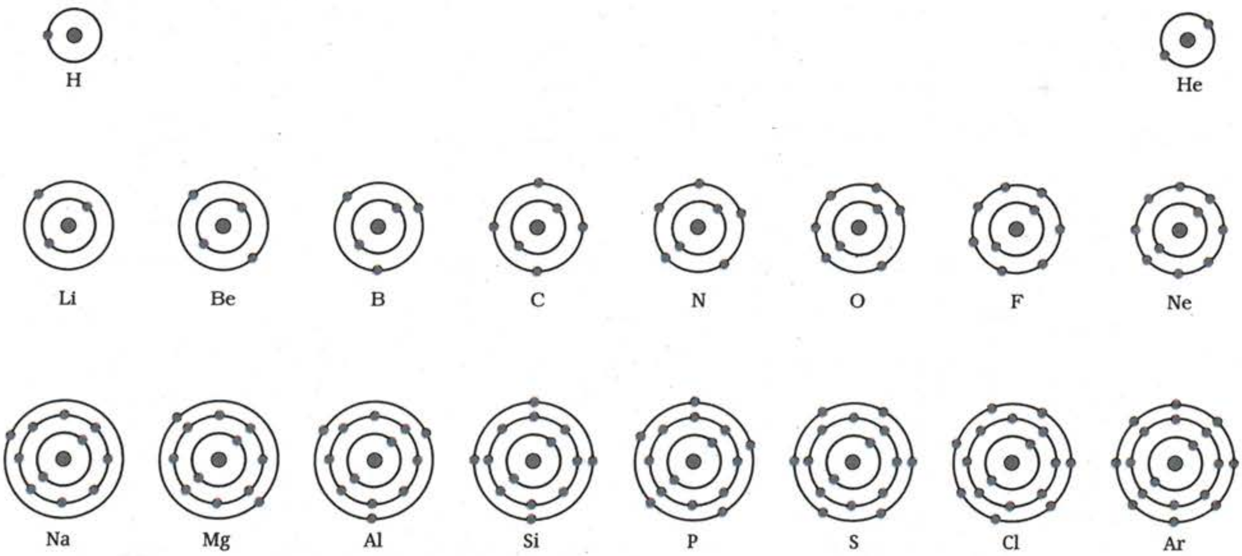


Fig. 8.11: Schematic atomic structure of the first eighteen elements showing how the electrons are filled in the K, L and M shells

Table 8.4: Symbols, atomic numbers, number of protons, number of neutrons, number of electrons, and the electronic distribution of atoms of the first eighteen elements

Name of the element	Symbol	Atomic number	Number of protons	Number of neutrons	Number of electrons	Distribution			
						K	L	M	N
Hydrogen	H	1	1	-	1	1	-	-	-
Helium	He	2	2	2	2	2	-	-	-
Lithium	Li	3	3	4	3	2	1	-	-
Beryllium	Be	4	4	5	4	2	2	-	-
Boron	B	5	5	6	5	2	3	-	-
Carbon	C	6	6	6	6	2	4	-	-
Nitrogen	N	7	7	7	7	2	5	-	-
Oxygen	O	8	8	8	8	2	6	-	-
Fluorine	F	9	9	10	9	2	7	-	-
Neon	Ne	10	10	10	10	2	8	-	-
Sodium	Na	11	11	12	11	2	8	1	-
Magnesium	Mg	12	12	12	12	2	8	2	-
Aluminium	Al	13	13	14	13	2	8	3	-
Silicon	Si	14	14	14	14	2	8	4	-
Phosphorus	P	15	15	16	15	2	8	5	-
Sulfur	S	16	16	16	16	2	8	6	-
Chlorine	Cl	17	17	18	17	2	8	7	-
Argon	Ar	18	18	22	18	2	8	8	-

Pause and Ponder

14. Identify the number of electrons in the outermost shell of the following elements:
    (i) $^{12}_{6}C$
    (ii) $^{19}_{9}F$
    (iii) $^{28}_{14}Si$
15. Write the electronic configuration of the elements having atomic numbers 12, 16 and 18.
16. Solve this riddle: I am an atom with a mass number of 23 and 11 protons. I am a soft metal and react vigorously with water. Who am I and how many neutrons do I have? You can also create one such riddle.

8.8 Combining Capacity of an Atom: Valency

You have learnt that atoms of the same or different elements can combine to form molecules. The number of atoms of hydrogen or chlorine with which one atom of an element can combine to form a compound is called its **combining capacity**. It is expressed in terms of hydrogen and chlorine because both possess a combining capacity of one. For example, in H_2O (water), oxygen combines with two hydrogen atoms, so the combining capacity of oxygen is two. In NH_3 (ammonia) and $MgCl_2$ (magnesium chloride), what will be the combining capacities of nitrogen and magnesium respectively? These examples show how the combining capacity of elements is determined by the number of hydrogen or chlorine atoms they combine with.

Grade 8 Curiosity Chapter 7

Let us learn how the combining capacity of an atom is decided by its electronic configuration.

The outermost shell containing electrons of an atom is known as its **valence shell**. The electrons present in it are known as **valence electrons**.

If the outermost shell of an atom has 8 electrons, it is called an **octet**. It has been observed that elements with complete octet of electrons (8 electrons), or 2 electrons in the case of helium in their valence shell are largely unreactive and more stable. On the other hand, atoms with incomplete valence shells are usually more reactive. Such elements lose, gain, or share electrons to complete their octet.

The number of electrons gained, lost, or shared to complete the octet is called the **valency** of the element. Generally, if the element has fewer than four electrons in its valence shell, it tends to lose electrons to complete its octet and become stable. On the other hand, if the number of valence electrons is more than four, it tends to gain electrons to complete its octet. For example, the electronic configuration of sodium is 2, 8, 1. It can get an octet by losing one electron. Therefore, its valency or combining capacity is 1. On the other hand, oxygen has an electronic configuration of 2, 6. It has six valence electrons. Therefore, it can gain two electrons to attain an octet, its valency is 2. The electronic configuration of carbon is 2, 4. Carbon has four valence electrons and cannot easily gain or lose them. Therefore, it can share four electrons with other atoms to complete its octet. Thus, the valency of carbon is 4. Some compounds appear to violate the usual valency rule, about which you will learn in higher grades.

Next Level Up

Can you **predict** what happens to the atoms that already have eight electrons in their outermost shell (except the elements with one shell only, where only two electrons are possible)? Will they still try to lose or gain electrons?

Examine Table 8.4. Add one more column to it, and write down the common valency of each element.

You have learnt that all the atoms of an element have the same number of electrons and protons, which is equal to its atomic number. Can you say the same regarding the number of neutrons too? Scientists have observed that atoms of the same element can have different numbers of neutrons. What effect does this difference have on the properties of the atom? Let us try to find out!

8.9 A Deeper Look into Atomic Structure

8.9.1 Isotopes

Dalton proposed that all atoms of an element are identical and have the same mass. But scientists later discovered that there were atoms of the same element that could have the same number of protons (atomic number, *Z*) yet could have different numbers of neutrons, and thus, different mass numbers ($A = p^+ + n^0$). These 'twin atoms' with the same atomic number but different mass numbers are called **isotopes**.

Let us take hydrogen as an example. Naturally occurring hydrogen is a mixture of three different isotopes: $^{1}_{1}H$ (protium, ~99.98%), $^{2}_{1}H$ (deuterium, ~0.015%), and $^{3}_{1}H$ (tritium, in traces) (Fig. 8.12). All of these contain one proton each, whereas deuterium contains one neutron, and tritium contains two neutrons. Can you guess how many electrons each of these isotopes have?

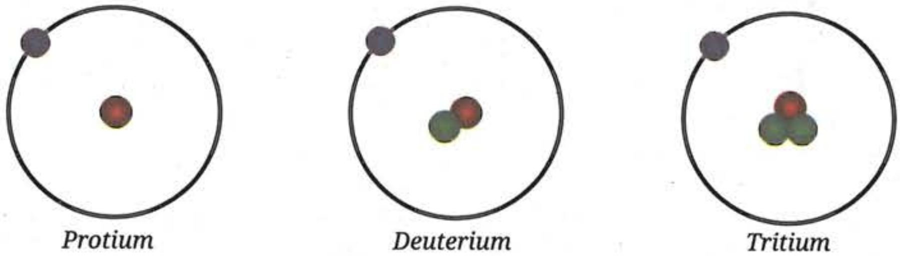


Fig. 8.12: Schematic representation of isotopes of hydrogen

Ready to Go Beyond

Atoms are too tiny to be weighed in kilograms or grams like everyday objects. Just as it is easier to weigh a grain of wheat in milligrams rather than kilograms, scientists use a special unit called the unified atomic mass unit (u) to measure the mass of atoms. This is because a kilogram is too large for such small particles. Earlier, atomic mass was expressed in atomic mass unit (abbreviated as 'amu').

The chemical properties of isotopes are similar. Do you know why? It is so because they have the same number of electrons and the same electronic configuration. As you have learnt, chemical properties depend mainly on the number of valence electrons. All the isotopes will have the same chemical properties although they differ in their physical properties, for example, boiling and melting points.

Similarly, carbon has three isotopes: $^{12}_{6}C$, $^{13}_{6}C$, and $^{14}_{6}C$ (Fig. 8.13). Each of these has six protons and six electrons. $^{12}_{6}C$ is the most abundant isotope in nature. You may note that these three isotopes differ in terms of the number of neutrons in them.

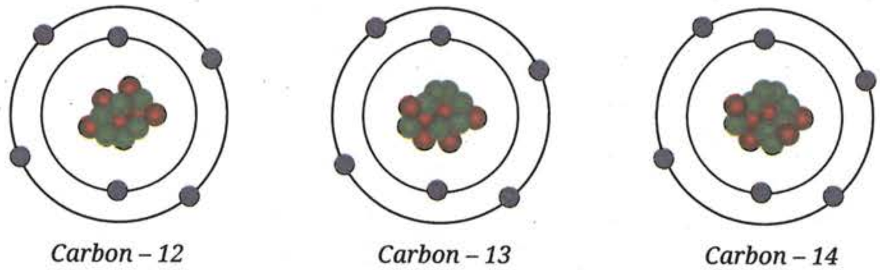


Fig. 8.13: Schematic representation of isotopes of carbon

Let us learn about the essential uses of some isotopes in our daily lives.

Bridging Science and Society

Some isotopes have special properties that are useful in various fields. Some of the applications of isotopes are:

Fig. 8.14: A nuclear power plant

- ${}^{235}_{92}U$, an isotope of uranium, is used as a fuel in a nuclear reactor to generate electricity in a nuclear power plant (Fig. 8.14).
- ${}^{60}_{27}Co$, a radioactive isotope of cobalt, is used in radiation treatment for cancer.
- ${}^{131}_{53}I$, an isotope of iodine, is used to treat goitre and thyroid cancer.
- ${}^{14}_{6}C$, an isotope of carbon, is used in archaeology and geology to determine the age of ancient fossils and artefacts.

A. Average atomic mass

Chlorine occurs in nature in two isotopic forms. One isotope has a mass of 35 u, and the other has a mass of 37 u. They occur in the ratio 3:1. This raises an interesting question — should we consider the mass of a chlorine atom to be 35 u or 37 u?

If the atomic mass of a natural element is taken as the **average mass** of all its naturally occurring isotopes, it would be the simple arithmetic mean of the masses of its isotopes, calculated without accounting for the relative abundances of each isotope. For chlorine, with isotopes ${}^{35}Cl$ and ${}^{37}Cl$, the simple average would be —

$$\text{Average atomic mass} = \left(\frac{35+37}{2}\right)$$

$$= 36 \text{ u}$$

However, this does not accurately reflect nature, since isotopes do not occur in equal ratios. The more common isotope is ${}^{35}Cl$, which constitutes about 75% while the other isotope, ${}^{37}Cl$ makes up about 25%. The accurate average atomic mass can be calculated by considering their natural abundances. This is called a **weighted average atomic mass**, which can be calculated by multiplying the mass of each isotope by its percent relative abundance and then adding the two values, as explained below.

Mathematically,

$$= \left(35 \times \frac{75}{100} + 37 \times \frac{25}{100}\right)$$

$$= \left(\frac{105}{4} + \frac{37}{4}\right) \text{u}$$

$$= \frac{142}{4} \text{ u}$$

$$= 35.5 \text{ u}$$

Meet a Scientist

Homi Jehangir Bhabha was an Indian physicist. He is known as the father of the Indian nuclear programme. He made a pioneering contribution to the development of atomic energy in India. He established key institutions like the Tata Institute of Fundamental Research (TIFR) and the Bhabha Atomic Research Centre (BARC), for peaceful uses of atomic energy to generate electricity, support agriculture, and advanced medical treatments.

Ready to Go Beyond

Electron microscopes, such as Scanning Tunnelling Microscopes (STMs) and Transmission Electron Microscopes (TEMs) can produce images of materials with atomic-level details. STMs mainly study surfaces (Fig. 8.15), while TEMs reveal how atoms are arranged inside very thin samples.

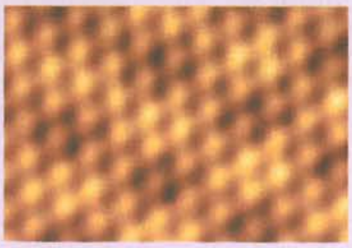


Fig. 8.15: STM image showing individual atoms on a surface

This does not mean that any one atom of chlorine has a fractional mass of 35.5 u. It means that if you take, say 1 million chlorine atoms, they will contain 7.5 lakh $^{35}_{17}Cl$ and 2.5 lakh $^{37}_{17}Cl$ atoms with a weighted average atomic mass of 35.5 u.

This comparison shows that the simple average ignores abundance, whereas the weighted average accurately reflects the mass of the element as it occurs in nature.

Pause and Ponder

17. Two different atoms have 11 protons each, but one has 12 neutrons, and the other has 13 neutrons. How do their atomic numbers and mass numbers compare? Are they the same element or different elements?
18. If a bromine atom is available in the form of, say two isotopes, $^{79}_{35}Br$ (49.7%) and $^{81}_{35}Br$ (50.3%), calculate the average atomic mass of the bromine atom.

You have learnt that the two atoms that have the same atomic number but different mass numbers are called isotopes. What if they have the same mass number but different atomic numbers? What are such atoms called? Let us find out!

8.9.2 Isobars

Let us consider three elements — calcium (atomic number 20), potassium (atomic number 19), and argon (atomic number 18). These elements have different numbers of protons, yet each has a mass number of 40. This shows that the total number of nucleons in their atoms is the same, even though they are different elements. When atoms of different elements have the same mass number, but different atomic numbers, they are called **isobars**.

As we end our journey into the structure of the atom, it is important to know that the story does not end here. The exploration of the structure of the atom is still being discovered (Fig. 8.16). Later, scientists discovered that even Bohr's model was not entirely correct. Electrons do not follow well-defined paths like the fixed Bohr orbits. Today, we understand that they exist as 'electron clouds' around the nucleus. We can predict regions where they are most likely to be, not exactly where they are. You will learn all these details in higher grades. The journey of exploring the mysteries of the atom is far from over, and exciting discoveries still lie ahead!

Next Level Up

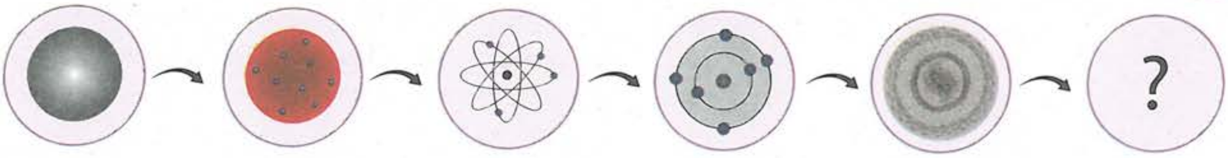


Fig. 8.16: Journey of the development of atomic models

At a Glance

- Atoms are the building blocks of matter.
- J. J. Thomson proposed that in an atom, electrons are embedded in a positively charged sphere.
- Rutherford's model described the atom as mostly empty space, with a dense, positively charged nucleus at its centre and electrons orbiting it.
- Niels Bohr's model proposed that electrons move in fixed energy levels (shells) around the nucleus.
- The shells of an atom are named as K, L, M, N, and so on.
- James Chadwick discovered the presence of neutrons in the atom.
- The three subatomic particles of an atom are electrons, protons, and neutrons.
- If the outermost shell of an atom has an octet of electrons (or two electrons in case of helium), the atom is stable and largely unreactive.
- Valency is the combining capacity of an atom. It is equal to the number of electrons which can be gained, lost or shared by an atom to achieve a stable configuration.
- The atomic number of an element is equal to the number of protons in its nucleus.
- The mass number of an atom is equal to the total number of nucleons (protons and neutrons) in its nucleus.
- Isotopes are atoms of same element that have the same atomic number but different mass numbers.
- The average atomic mass of an element is calculated based on the relative abundance of its isotopes in nature.
- Isobars are atoms of different elements with the same mass number but different atomic numbers.

Revise, Reflect, Refine

1. Choose the **correct** options and explain the reason for the correct and incorrect options in the context of Ernest Rutherford's gold foil experiment:
   (i) The experiment clearly showed the existence of neutrons in the nucleus.
   (ii) The results disproved the plum pudding model and led to the idea of a nucleus at the centre of the atom.
   (iii) The large deflection of a few alpha particles indicated that most of the mass of the atom and positive charge are packed into a tiny centre.
   (iv) The way alpha particles were deflected showed that electrons move around the nucleus.
2. Which of the following statements are **correct** or **incorrect** according to the Bohr's atomic model? Give a reason for each statement.
   (i) Electrons lose energy while moving in fixed orbits and slowly fall into the nucleus.
   (ii) Electrons can exist anywhere around the nucleus with no fixed energy.
   (iii) Electrons revolve around the nucleus in orbits of fixed energy without losing energy.
   (iv) Electrons can be found between energy levels as they move around the nucleus.
3. The composition of the nuclei of three atomic species X, Y, and Z are given as follows.

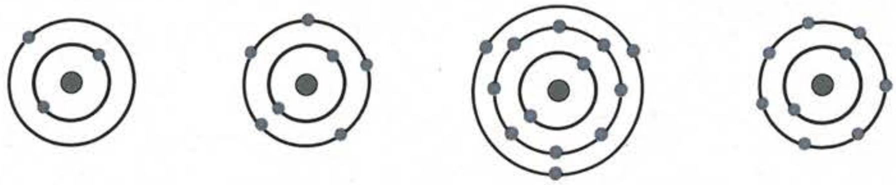
	X	Y	Z
Number of protons	18	17	17
Number of neutrons	19	18	20

   Explain the relation between the following:
   (i) Y and Z
   (ii) Z and X
4. What conclusion did Rutherford draw about the position and characteristics of the atom's positively charged part based on the few alpha particles that bounced back or were deflected at large angles in the gold foil experiment?

5. Explain and arrange the following statements in the correct chronological order to show how atomic models have evolved over time.
   (i) Bohr's model proposed that electrons move in fixed orbits around the nucleus, each with a definite energy.
   (ii) Thomson's model depicted the atom as a 'plum pudding' with electrons embedded in a sphere of positive charge.
   (iii) Rutherford's model proposed that atoms have a dense central nucleus.
   (iv) Dalton's model described atoms as indivisible particles.
6. Electrons move around the nucleus in orbits. Why do they not fly away from the atom? Explain what keeps them attracted to the nucleus.
7. Assertion (A): The discovery of subatomic particles helped in understanding the atomic structure.

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

   Choose the correct option:
   (i) Both A and R are true, and R is the correct explanation of A.
   (ii) Both A and R are true, but R is not the correct explanation of A.
   (iii) A is true, but R is false.
   (iv) A is false, but R is true.
8. Magnesium is essential for many biological processes, including muscle contraction. For an atom of magnesium with a mass number of 24 and atomic number 12, determine the number of (i) protons, (ii) neutrons, (iii) electrons, and also illustrate the arrangement of electrons in a magnesium atom.
9. Find the following information for the elements shown in Fig. 8.17:
   (i) Name of the element
   (ii) Symbol
   (iii) Total number of electrons
   (iv) Number of valence electrons
   (v) Valency of the element
   (vi) Number of protons
   (vii) Atomic number



(a) (b) (c) (d)

Fig. 8.17

10. Both Rutherford's and Bohr's models have electrons orbiting the nucleus. Why did Rutherford's model fail to explain atomic stability, while Bohr's model succeeded?
11. An atom ^{70}X has 31 electrons. How many neutrons are there in its nucleus?
12. An atom has 79 protons and a mass number of 197. Calculate (i) the number of neutrons, and (ii) the number of electrons.
13. Complete the Table 8.5:

Table 8.5

Atomic number	Mass number	Number of neutrons	Number of protons	Number of electrons	Name of the elements
5	–	6	–	–	–
–	14	–	–	7	Nitrogen
–	24	–	12	–	–
15	–	16	–	–	–
–	1	0	–	–	–

14. Aman was discussing the structure of atom with his classmates. During the discussion, he learnt that an element X has a mass number of 35 and contains 18 neutrons. Based on this information, answer the following questions:
    (i) How many electrons and protons does element X have?
    (ii) What is its atomic number?
    (iii) Identify the element X.
    (iv) Write its electronic configuration.
    (v) How many valence electrons does it have?
    (vi) What will be the mass number if two neutrons are added to its nucleus?
    (vii) What will be the relation of X with the new atom?
15. In an atom, there are 12 protons and 12 neutrons in the nucleus. Now, imagine that all the electrons are replaced with some hypothetical particles that have the same charge as electrons but are 500 times heavier. What effect will this replacement have on the atom's:
    (i) Atomic number
    (ii) Atomic mass
    (iii) Mass number
    (iv) Overall charge

The Journey Beyond

- Create an 'Atomic Prediction Board' game based on atomic number, mass number, number of electrons, protons, neutrons and valency. Students may predict elements using atomic clues.
- Prepare a report on how the properties of atoms impact us in everyday life across fields, such as healthcare, energy, agriculture and technology.
- Create a role-play stage play or story about the 'Journey Inside the Atom', and the scientists who discovered and contributed to the identification of atomic structure.
- Use selected software or digital tools and try to create animations or simulations of various atomic models, and share them in the class.
- Watch a film or documentary about the structure of the atom and write a report answering the following questions:
    - Which film or documentary did you watch, and what was its main idea or topic?
    - What did the film or documentary teach you about the structure of the atom and the atomic model(s)?
    - Which scientists were mentioned in the film or documentary, and what were their contributions?
    - What part of the film or documentary did you find most interesting, and what question do you still have?
- Draw a bar graph showing the number of electrons in each energy level for any three elements.
- To learn more about atoms, you can explore the links given below:
    - https://phet.colorado.edu/en/simulations/rutherford-scattering
    - https://phet.colorado.edu/en/simulations/isotopes-and-atomic-mass

The Quest Continues ...

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

0906CH09

Chapter 9

Atomic Foundations of Matter

Think It Over

- Water can be obtained from various sources. Are all these samples of water chemically identical?
- Oxygen is sometimes represented as O and sometimes as O_2. What is the difference between these symbols?
- Why does dissolved salt in water conduct electricity, but sugar does not?

In Chapter 8, Journey Inside the Atom, you explored the structure of the atom. You also studied subatomic particles, viz., electrons, protons and neutrons, in terms of their discoveries, properties and locations in the atom. You also learnt that atoms with an octet of electrons in their valence shell are stable. Atoms can lose, gain or share electrons to achieve an octet of valence electrons.

Grade 8 Curiosity Chapter 8

You have also learnt that many properties of the elements are not retained when they form a compound. For example, hydrogen and oxygen are gases, whereas the substance formed when they combine is water, which is a liquid at ordinary temperatures.

Interestingly, water does not have the same properties as hydrogen or oxygen. Hydrogen gas is combustible and oxygen supports combustion, whereas water neither burns nor helps in burning; rather, it extinguishes fire. However, it was found that the mass of the water formed equals to the sum of the masses of the hydrogen and oxygen that combined to form it. Let us **explore** whether the mass remains unchanged during physical and chemical changes.

Activity 9.1: Let us investigate a physical change

1. Place a clean and dry 100 mL beaker on a digital weighing balance.
2. Set the balance reading to zero by pressing the tare or reset button.
3. Pour about 50 mL of water into the beaker.
4. Add a spatula full of common salt to the water contained in the beaker.
5. **Record** the reading on the weighing balance (Fig. 9.1a).
6. Swirl until the added salt dissolves and record your observations (Fig. 9.1b).

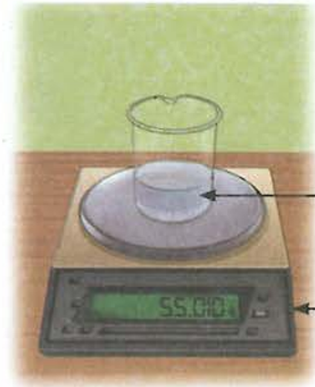


Fig. 9.1: (a) Weight of water and undissolved salt

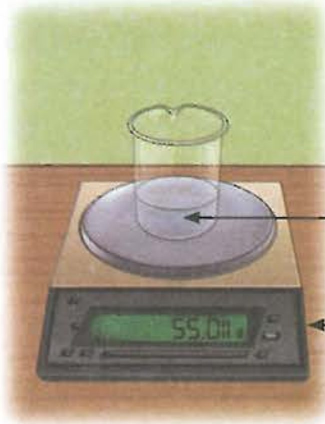


Fig. 9.1: (b) Weight of solution of salt and water

What do you **observe**? You may **notice** that the mass of the solution is equal to the sum of the masses of water and salt taken. This shows that there is practically no change in the mass during the formation of a solution, which is a physical change. This is true for all physical changes. You can repeat the above activity by weighing a piece of paper before and after tearing it into pieces, and observe whether its mass changes or not.

Now, let us find out whether this is true for chemical changes as well.

Activity 9.2: Let us investigate a chemical change

You have learnt about various chemical changes. Do you remember what happened when baking soda was added to vinegar? A gas, carbon dioxide, was formed during this chemical change and the reaction is represented as —

Grade 7 Curiosity Chapter 5

Vinegar + Baking soda (Sodium hydrogencarbonate) → Carbon dioxide + Other substances

Let us explore whether the mass remains the same before and after the change.

Experimental set-up 1

1. Place a clean, dry 100 mL conical flask and a medium-sized balloon on a weighing balance.
2. Set the balance reading to zero by pressing the tare or reset button.
3. Pour about 20 mL of vinegar or lemon juice into the conical flask.
4. Take about 2 g of baking soda (sodium hydrogencarbonate) and put it into the balloon.
5. Keep the balloon filled with baking soda on the weighing balance next to the conical flask. Record the initial reading (Fig. 9.2a).

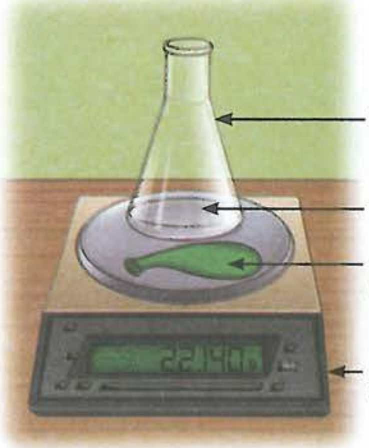


Fig. 9.2: (a) Weight of vinegar and baking soda

Note

Usually in any measurement, there is uncertainity of ±1 in the last digit. Therefore, the variation in readings of digital weighing balance is within experimental error and the weight can be taken as constant.

Fig. 9.2: (b) Pouring baking soda into the conical flask containing vinegar

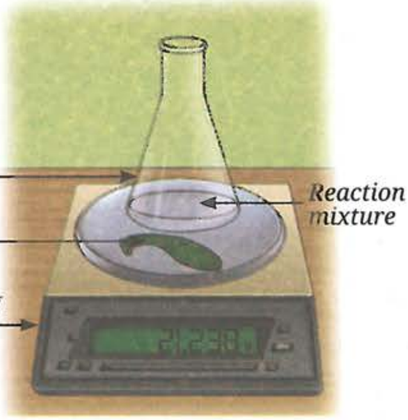


Fig. 9.2: (c) Weight of the final reaction mixture

6. Carefully transfer the baking soda (sodium hydrogencarbonate) from the balloon into the conical flask containing vinegar (Fig. 9.2b).
7. Place the conical flask and balloon back on the weighing balance, and record the final reading (Fig. 9.2c).

Note

Keep the conical flask and the balloon on the digital weighing balance. This prevents errors caused by small traces of baking soda that may remain stuck to the balloon.

8. What do you observe?
9. Are the initial and the final readings same?

A brisk effervescence is observed. The final reading does not match the initial reading. What can be the reason for this?

Repeat the above experiment in a slightly modified way as explained below.

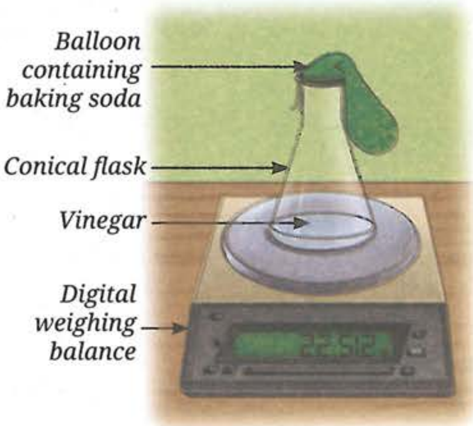


Fig. 9.3: (a) Weight of vinegar and baking soda

Experimental set-up 2

1. Place a clean, dry 100 mL conical flask and a medium-sized balloon on a weighing balance.
2. Set the balance reading to zero by pressing the tare or reset button.
3. Pour about 20 mL of vinegar or lemon juice into the conical flask.
4. Place about 2 g of baking soda (sodium hydrogencarbonate) in the balloon.
5. Fix the balloon to the mouth of the conical flask using a thread, without allowing the baking soda to mix with the vinegar.
6. Weigh the conical flask containing vinegar and the balloon containing baking soda, and record the reading (Fig. 9.3a).
7. Lift the other end of the balloon upwards, allowing the baking soda (sodium hydrogencarbonate) to fall into the vinegar (Fig. 9.3b).
8. What do you observe?

Fig. 9.3: (b) Pouring baking soda into the conical flask containing vinegar

9. As in experimental set-up 1, a brisk effervescence occurs, which inflates the balloon during the reaction.
10. Record the final reading (Fig. 9.3c).
11. Are the initial and the final readings same in this case?

In this experiment, the final reading matches the initial reading. You have noticed that the total mass of vinegar and baking soda (sodium hydrogencarbonate) before the chemical reaction is equal to the total mass of carbon dioxide and other substances formed after the reaction. In experimental set-up 1, the mass difference occurs because the gas produced by the chemical reaction escapes, resulting in a difference between the initial and the final readings.

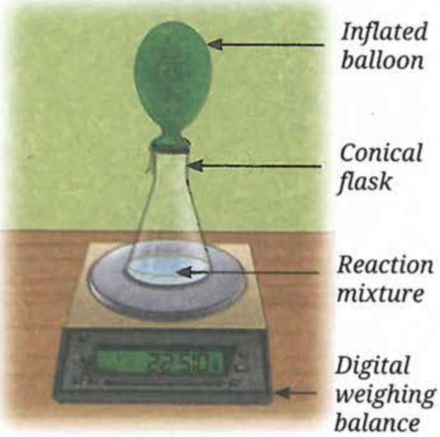


Fig. 9.3: (c) Weight of the final reaction mixture

9.1 Law of Conservation of Mass

The Activity 9.2 demonstrates that the total mass remains the same before and after a chemical reaction. So, matter can neither be created nor destroyed in a chemical reaction. This is known as the **Law of Conservation of Mass**, proposed by Antoine Lavoisier in 1789.

Meet a Scientist

Antoine Lavoisier is known as the Father of Modern Chemistry. He proposed the Law of Conservation of Mass. This law applies to every chemical reaction. Lavoisier continued to study this and proposed that "...*in every operation an equal quantity of matter exists both before and after the operation*".

Let us consider the reaction between sodium sulfate and barium chloride to further verify this law.

Activity 9.3: Let us verify the law — Group activity

1. Place two clean and dry 100 mL conical flasks on a weighing balance, and mark them A and B.
2. Set the balance reading to zero by pressing the tare or reset button.
3. Pour about 10 mL of 1 % *m/v* sodium sulfate solution into the Conical Flask marked A.
4. In the Conical Flask B, pour about 10 mL of 1 % *m/v* barium chloride solution.
5. Leave both Conical Flasks A and B on the weighing balance undisturbed, and record the total mass of both the solutions (Fig. 9.4a).
6. Transfer the solution from Conical Flask B to Conical Flask A and mix the two solutions carefully.
7. What do you observe?
8. Now, place both the Conical Flasks A and B on the weighing balance again as shown in Fig. 9.4b, and note the reading.
9. Do you observe any change in the reading after mixing the solutions?

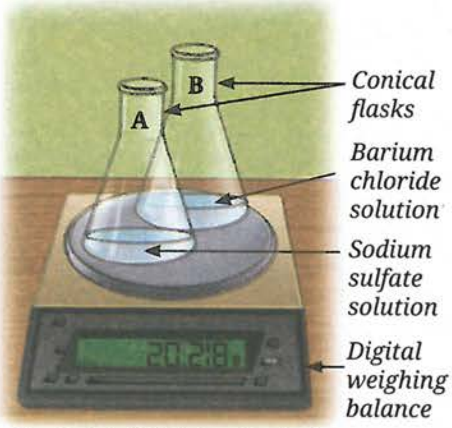


Fig. 9.4: (a) Weight of solutions (reactants) before mixing

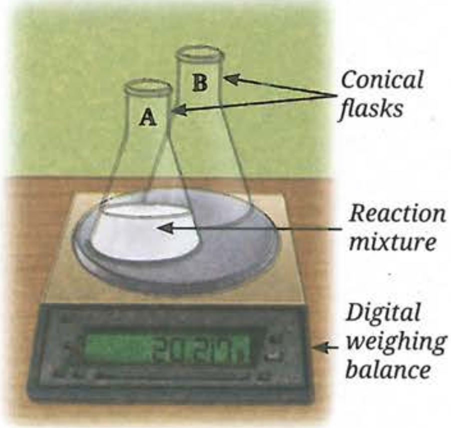


Fig. 9.4: (b) Weight of products after mixing

Note

- Keep both the conical flasks on the digital weighing balance. It prevents the error caused by a small amount of solution that may remain stuck to the walls of the conical flask during transfer.
- This reaction has been carried out in the open system, since no gas is formed.

When solutions of sodium sulfate and barium chloride are mixed, a white precipitate of barium sulfate is formed along with sodium chloride. It can be represented as—

Sodium sulfate + Barium chloride → Barium sulfate + Sodium chloride

Based on the Activity 9.2, it was established that weight and hence, mass is conserved during a chemical change (chemical reaction).

Think as a Scientist

You are given a chemical reaction in which zinc reacts with dilute hydrochloric acid to form zinc chloride and hydrogen gas.

Zinc + Hydrochloric acid (dilute) → Zinc chloride + Hydrogen

Design and perform an experiment to test the **hypothesis** that mass is conserved during the chemical reaction. You may use a set-up different from the one shown in Activity 9.2.

Example 9.1: In a group activity, students place 4.0 g of calcium carbonate with 2.92 g of hydrochloric acid in a closed container. After the reaction is over, they measured 1.76 g of carbon dioxide, 0.72 g of water, and 4.44 g of calcium chloride. Verify whether the Law of Conservation of Mass is obeyed or not.

Solution: Mass of calcium carbonate = 4.0 g

Mass of hydrochloric acid = 2.92 g

Total mass of reactants: 4.0 g + 2.92 g = 6.92 g

Mass of carbon dioxide = 1.76 g

Mass of water = 0.72 g

Mass of calcium chloride = 4.44 g

Total mass of products: 1.76 g + 0.72 g + 4.44 g = 6.92 g

Compare the total mass of reactants with the total mass of products.

Mass of reactants = Mass of products

Hence, the Law of Conservation of Mass is obeyed.

Pause and Ponder

1. A student burns 10 g of ethanol in an open beaker. After the reaction, no residue is left in the beaker. Does this mean the Law of Conservation of Mass is violated? Explain.
2. When 20 g of hydrogen reacts completely with 160 g of oxygen, how much water is formed according to the Law of Conservation of Mass?

Example 9.2: 12 g of carbon combines with 32 g of oxygen to form 44 g of carbon dioxide as per the given equation.

Carbon + Oxygen → Carbon dioxide

If 2.4 g of carbon reacts completely with oxygen, how much carbon dioxide will be produced?

Solution: Given that 12 g of carbon reacts with 32 g of oxygen to give 44 g of carbon dioxide.

So, 1 g of carbon will give $= \frac{44}{12}$ g of carbon dioxide

Thus, 2.4 g of carbon will give $= \frac{44}{12} \times 2.4$ g

$= 8.8$ g of carbon dioxide

Hence, 8.8 g of carbon dioxide will be produced.

In the above activities, we have used many compounds. Let us learn how these are formed from the elements. Let us take an example of water, is there a fixed ratio in which hydrogen can combine with oxygen to form it, or can they combine in any ratio? This leads us to another important law.

9.2 Law of Constant Proportions

Soon after Lavoisier, Joseph Proust proposed that in any compound formed by two or more elements, the elements combine in a fixed ratio by mass. In other words, elements in a compound have definite proportions irrespective of its source. For example, if the water collected from various sources, such as rivers, borewells or the ocean, is purified and analysed. It is always found to contain hydrogen and oxygen in a mass ratio of 1:8. What does it convey? If 9 g of purified water from any source is decomposed, 1 g of hydrogen and 8 g of oxygen are always obtained. This proportion is written as 1:8.

This is known as the **Law of Constant Proportions**, or the **Law of Definite Proportions**, or sometimes as **Proust's Law**.

Meet a Scientist

Joseph Louis Proust was a prominent French chemist known for his careful experimental work. He contributed to the Law of Definite Proportions by showing that chemical compounds always contain elements in fixed ratios by mass. For example, Proust studied the composition of copper carbonate. He showed that copper carbonate always contains copper, carbon and oxygen in the same proportion by mass, no matter how it was prepared or where it was found. His work laid an important foundation that helped shape modern chemistry.

Threads of Curiosity

In many ancient civilisations, red pigment derived from rocks was widely used in painting and as a colouring agent for various objects. In India, it was known as *hingula*, and in Latin and English, as cinnabar. Over the centuries, it was discovered in many civilisations that heating cinnabar could yield two elements — mercury and sulfur in mass percentage of around 86.22% and 13.78%, respectively. Interestingly, most civilisations also found that grinding mercury and sulfur together in this ratio could form cinnabar, although the toxic nature of both prevented this process from becoming widespread.

Fig. 9.5: Cinnabar

Example 9.3: Sodium chloride (NaCl) contains sodium and chlorine in the mass ratio of 23:35.5. If 46 g of sodium reacts completely, how much chlorine is needed to form NaCl?

Solution: Mass of chlorine required = (35.5 ÷ 23) × 46 = 71 g

Pause and Ponder

3. A compound consists of 40% sulfur and 60% oxygen by mass. In a sample of the same compound containing 20 g of sulfur, what mass of oxygen must be present to satisfy the Law of Constant Proportions?
4. Carbon monoxide (CO) contains carbon and oxygen in the mass ratio of 3:4. How much oxygen will combine with 9 g of carbon to form carbon monoxide?
5. The Law of Definite Proportions holds true for compounds but not for mixtures. Give reason.
6. Students X and Y, both prepared an oxide of copper by combining copper and oxygen in the ratios of 4:1 and 8:2, respectively. Do their results justify the Law of Constant Proportions? Explain.

What if ...

atoms could combine in any ratio and not in a fixed ratio? How would this affect the substances around us?

The two laws discussed here formed the basis of **Dalton's Atomic Theory**. This theory attempts to logically explain why substances combine in fixed proportions and why there is no loss or gain of mass during a chemical reaction. Dalton later explained these by proposing that during a chemical reaction, atoms are indivisible and merely rearrange, rather than being created or destroyed.

9.3 Dalton's Atomic Theory

John Dalton proposed his atomic theory in terms of certain postulates. These postulates combined earlier experimental observations and served as the basis for modern scientific theory. A postulate is a fundamental assumption accepted as truth without formal proof from which further ideas are formed or developed.

Meet a Scientist

John Dalton was born in England. In 1793, Dalton moved to Manchester to teach mathematics, physics and chemistry at a college. He spent most of his life teaching and researching there. In 1808, he presented his atomic theory, which proved to be a turning point in the study of matter.

John Dalton postulated that:

- All matter is made up of very tiny particles called atoms, which participate in chemical reactions.
- Atoms are indivisible particles, which 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 have different masses and chemical properties.
- Atoms combine in the ratio of simple whole numbers to form compounds.
- The relative number and kinds of atoms are constant in a given compound.

Dalton's postulates provide the basis for the modern understanding of atoms and their behaviour.

For example, hydrogen and oxygen atoms combine to form water, but the atoms themselves are not destroyed or changed into something else. Similarly, when magnesium burns in air, a white powder of magnesium oxide forms. This shows that the atoms of magnesium have combined with those of oxygen to form magnesium oxide.

Pause and Ponder

7. Assertion (A): 2 g of hydrogen combines with 16 g of oxygen to form 18 g of water.
   Reason (R): According to Dalton's Atomic Theory, atoms combine in a simple whole number ratio by mass to form compounds.
   Choose the correct option:
   (i) Both A and R are true, and R is the correct explanation of A.
   (ii) Both A and R are true, but R is not the correct explanation of A.
   (iii) A is true, but R is false.
   (iv) A is false, but R is true.

Later, scientists discovered how atoms combine to form **molecules**. Let us explore further!

9.4 How Atoms Combine?

Atoms of an element can combine to form a molecule of that element. For example, a hydrogen molecule consists of two hydrogen atoms. Atoms of different elements combine to form a molecule of a compound. For example, one hydrogen atom and one chlorine atom combine to form a molecule of hydrogen chloride. A molecule can be defined as an electrically neutral entity consisting of more than one atom that is capable of independent existence and shows all the properties of that substance. It should also be remembered that some elements, such as helium, exist only as atoms because its atoms are stable.

In Chapter 8, Journey Inside the Atom, you learnt that atoms with 8 electrons in the outermost (valence) shell (2 electrons if the K-shell is the outermost shell) are stable. If the number of electrons in a valence shell is less than eight, then they may share, gain or lose electrons to complete their valence shell and become stable. In this process, atoms of elements combine to form compounds. This generally takes place in two ways. These are:

- **Sharing of electrons** — Share a few or all of their valence electrons with another atom.
- **Transfer of electrons** — Transfer one or more of the valence electrons to another atom, or accept one or more electrons from some other atom.

When atoms combine, the total energy of the system becomes lower than the sum of the energies of the individual atoms, making the resulting arrangement more stable. The force that holds atoms together is called a **chemical bond**. Let us explore it further.

9.4.1 Bonding by sharing of electrons — Covalent Bond

A. Molecules of elements

Let us understand the formation of molecules of elements by the sharing of electrons, as described below.

Consider the formation of a hydrogen molecule:

- Write the electronic configuration of hydrogen (atomic number 1). It has only one electron in the K-shell.
- Since, a K-shell can have a total of two electrons, it needs one more electron to become stable.

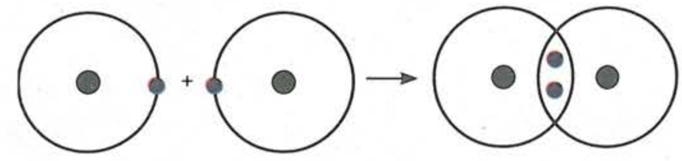


Fig. 9.6: Formation of a hydrogen molecule

Thus, a hydrogen atom shares one electron with another hydrogen atom to form a hydrogen molecule (H_2), as shown in Fig. 9.6. The shared pair of electrons attracts both the nuclei and makes the molecule stable. This type of interaction between atoms through a shared pair of electrons is called a **covalent bond**. If two atoms are joined by sharing one electron each, they are said to be joined by a **single bond**.

This is generally depicted by drawing a single line between the symbols of the two atoms as H—H.

Let us take the case of a chlorine molecule.

Pause and Ponder

8. Nitrogen has five valence electrons. Draw the structure of the nitrogen molecule (N_2).
9. The atomic number of fluorine is 9. Explain the formation of the fluorine molecule (F_2).

Together we are strong ...

Just as atoms share electrons to form covalent bonds, we too, can share and care to build strong relationships with people around us. This sharing brings unity and stability, laying the foundation for a stronger community, and ultimately, a strong nation.

The chlorine atom has seven electrons in its valence shell. Each chlorine atom requires one electron to attain a stable electronic configuration. A chlorine molecule is formed by the sharing of one electron each by two chlorine atoms, as shown in Fig. 9.7. This shared pair of electrons holds the two chlorine atoms together as a molecule.

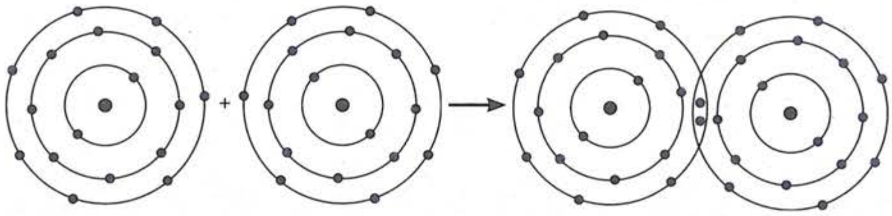


Fig. 9.7: Formation of a chlorine molecule

Since, the two atoms that share one electron pair are said to be bonded by a single covalent bond, the chlorine (Cl_2) molecule can be represented as Cl—Cl.

Let us explore the bonding in an oxygen molecule.

Write down the electronic configuration of the oxygen atom (atomic number 8). You can observe that the number of electrons present in its valence shell is six, and it requires two more electrons to complete its octet.

So, two oxygen atoms share two electrons each, forming an oxygen molecule (O_2), as shown in Fig. 9.8.

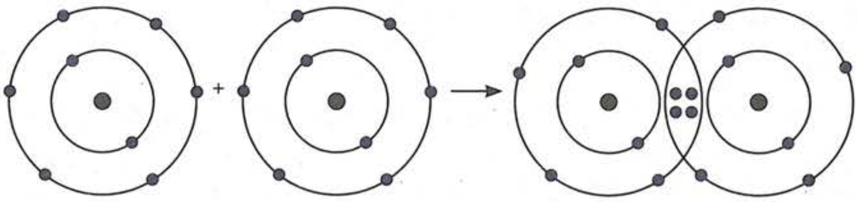


Fig. 9.8: Formation of an oxygen molecule

In this case, the two atoms are joined by two pairs of shared electrons, and are held together by a **double bond**. It can be depicted by drawing two lines between two oxygen atoms as O=O.

B. Molecules of compounds

In the section 9.4.1A, you learnt about the formation of molecules of elements, where two atoms of the same element combine. What happens if atoms of two different elements combine? Let us understand by taking an example of the formation of hydrogen chloride molecule.

You can do it by using the following steps:

- Write the electronic configurations of hydrogen and chlorine atoms (atomic number of hydrogen is 1 and chlorine is 17).
- Calculate the number of electrons required by chlorine to complete its octet and by hydrogen to complete its duplet.

You must have noticed that atoms of both hydrogen and chlorine need one electron each to attain stable electronic configurations. Hence, both the atoms share one electron each to form a molecule of hydrogen chloride, as shown in Fig. 9.9.

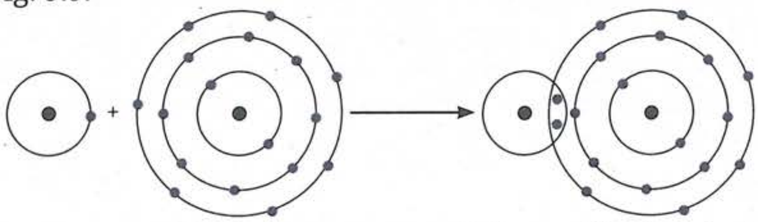


Fig. 9.9: Formation of a hydrogen chloride molecule

Since the hydrogen and chlorine atoms in a hydrogen chloride (HCl) molecule bond by sharing electrons, it is a covalent compound. Also, since hydrogen and chlorine atoms share one pair of electrons, they are bonded by a single bond and it can be depicted as H—Cl.

You know that hydrogen and oxygen combine to form water. Hydrogen needs only one electron, while oxygen needs two electrons to acquire stable electronic configurations. How can oxygen share its two electrons with another atom that requires only one electron? This is achieved by two hydrogen atoms sharing an electron each with an oxygen atom, as shown in Fig. 9.10.

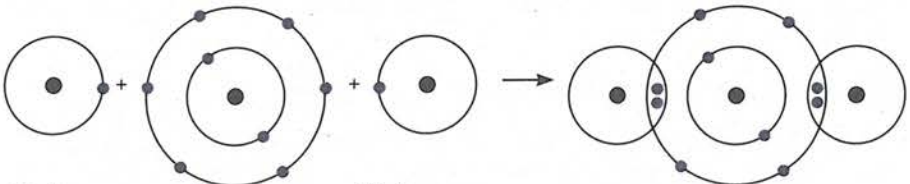


Fig. 9.10: Formation of a water molecule

Thus the water molecule formed is represented as H_2O, which indicates the presence of two hydrogen atoms and one oxygen atom.

Pause and Ponder

10. Show the formation of the following molecules:
    (i) Carbon dioxide (CO_2)
    (ii) Hydrogen sulfide (H_2S)
    (iii) Ammonia (NH_3)
11. Neon (atomic number 10) neither transfers nor shares its valence electrons. Explain.

Bridging Science and Society

Atoms can release enormous energy when their nuclei split or combine to form new elements. This is called atomic or nuclear energy, and it plays a vital role in modern life. Beyond electricity generation, it is used in medicine, scientific research and space exploration. In nuclear power plants, the thermal energy from nuclear reactions produces steam that drives turbines and generates electricity, a cleaner alternative to fossil fuels. In India, scientists like **Raja Ramanna** (often called the Father of the Indian Nuclear Programme) made significant contributions in developing the nation's Nuclear Energy Programme and promoting its peaceful use for development.

C. Naming covalent compounds

Covalent compounds are named by indicating the number of atoms of each element in the compound. To name these compounds, a prefix system is used to indicate the number of atoms of each element in the molecule. The first element retains its regular name, while the second element ends in -ide. Prefixes, such as mono- (1), di- (2), tri- (3), tetra- (4), penta- (5), hexa- (6), etc., indicate the number of atoms. However, mono- is usually omitted for the first element but is used for the second element. If a prefix ends with 'o' or 'a' and the element starts with a vowel, drop the last vowel (for example, monoxide, pentoxide). If the prefix ends with 'i', keep it for pronunciation (for example, dioxide, trioxide).

Examples

- CO is named as carbon monoxide (not monooxide).
- CO_2 is named as carbon dioxide (not monocarbon dioxide).
- CS_2 is named as carbon disulfide, showing two sulfur atoms.
- PCl_3 is named as phosphorus trichloride, showing three chlorine atoms.
- SF_6 is named as sulfur hexafluoride, showing six fluorine atoms.
- N_2O_4 is named as dinitrogen tetroxide (not tetraoxide).
- N_2O_5 is named as dinitrogen pentoxide.

When hydrogen is the first element in the formula, no prefix is added before hydrogen, irrespective of the number of its atoms. For example, H_2S is named hydrogen sulfide, not dihydrogen sulfide.

A few binary compounds are known only by their common names. For example, H_2O, which would usually be named hydrogen monoxide, is commonly known as water. Similarly, NH_3, which is actually nitrogen trihydride, is known as ammonia.

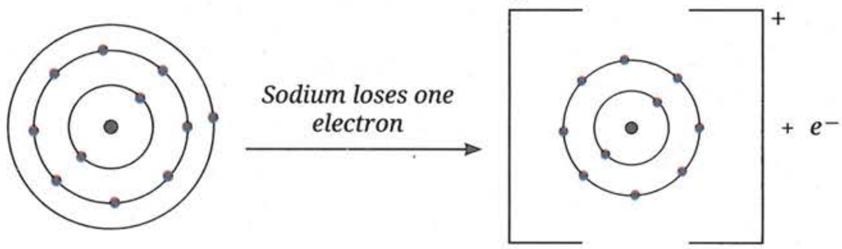
9.4.2 Bonding by electron transfer — Ionic bond

If the valence shell of an atom has less than four electrons, it would generally donate its valence electrons to achieve a stable electronic configuration. Identify four such elements among the first 18 elements by using their electronic configurations given in Table 8.4 of the Chapter 8, Journey Inside the Atom. Atoms with more than 4 valence electrons usually gain or share electrons to complete an octet.

You are familiar with sodium chloride (common salt), whose chemical formula is NaCl. Let us take the bonding in NaCl as an example.

The atomic number of sodium is 11. Its valence shell contains only one electron, which can attain a stable electronic configuration after losing this valence electron. Will it still be neutral after losing one electron? If not, what charge would it carry and why?

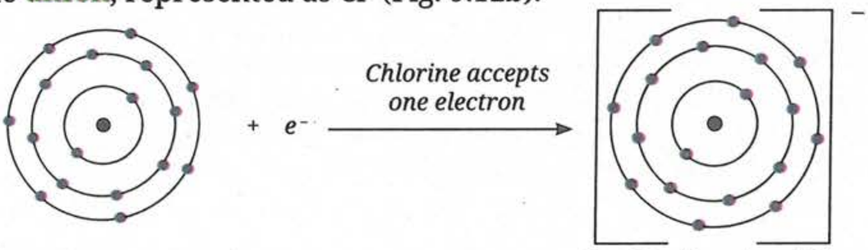
When sodium atom (Fig. 9.11a) loses its valence electron, it becomes a positively charged species, called a sodium **cation**, represented as Na^+ (Fig. 9.11b). It is so because it would have 11 protons and 10 electrons.



(a) Sodium atom (Na) *(b) Sodium cation (Na^+)*

Fig. 9.11: Formation of a sodium cation

On the other hand, the electronic configuration of a chlorine atom shows that it has seven valence electrons (Fig. 9.12a). It can attain a stable electronic configuration by gaining one electron from another atom. After gaining one extra electron, it acquires a negative charge and is called a chloride **anion**, represented as Cl^- (Fig. 9.12b).



(a) Chlorine atom (Cl) *(b) Chloride anion (Cl^-)*

Fig. 9.12: Formation of a chloride anion

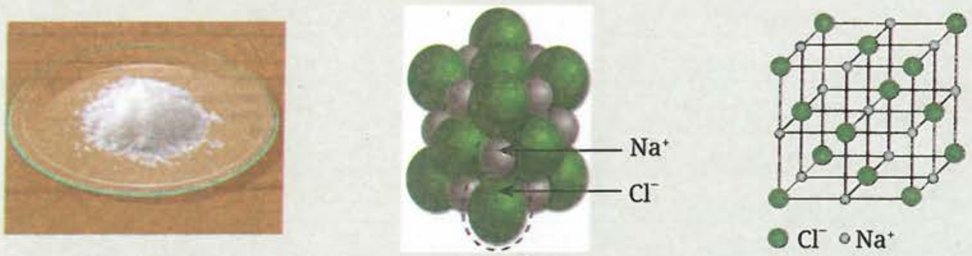
Cations and anions are collectively called ions. Once the sodium and chloride ions are formed, they are held together by the electrostatic force of attraction due to their opposite charges (Fig. 9.13). The electrostatic force of attraction between oppositely charged ions that holds them together is called an **ionic bond**.

$$Na\cdot + :\ddot{\underset{..}{Cl}}: \longrightarrow Na^+ + [:\ddot{\underset{..}{Cl}}:]^- \longrightarrow NaCl$$

Fig. 9.13: Formation of sodium chloride by transfer of electron

Threads of Curiosity

Ionic compounds usually do not remain as single units. They form three-dimensional (3-D) crystals in which ions are arranged in a repeating pattern. For example, in sodium chloride (NaCl), each sodium ion (Na^+) is surrounded by six chloride ions (Cl^-), and each chloride ion is surrounded by six sodium ions (Fig. 9.14a). These oppositely charged ions are arranged in a regular, repeating 3-D pattern known as a crystal structure (Fig. 9.14b).



(a) (b) (c)

Fig. 9.14: Sodium chloride: (a) crystals, (b) crystal structure, and (c) crystal lattice

The crystal structure is represented as a crystal lattice, with ions depicted as points or dots (Fig. 9.14c). It helps to visualise the arrangement of ions in the crystal. You will learn more about the crystal structure in higher grades.

Next Level Up

Some elements like sulfur have six electrons in their outer shell and need to gain two electrons to complete their octet. When a sulfur atom gains two electrons, it acquires two units of negative charge and is represented as S^{2-}.

What if ...

we could see atoms directly? How would it help scientists and what challenges would it cause?

Pause and Ponder

12. What kind of ion will oxygen (O) form?
13. Fill in the blanks.

    Among magnesium and chlorine, magnesium atom can give two electrons to become Mg^{2+}. However, chlorine can take only one electron to become ___________. Now, _________ ion of magnesium and _________ ions of chlorine combine to give magnesium chloride.
14. Show the formation of cations of potassium (K) and calcium (Ca) atoms, and the formation of their corresponding chlorides using diagrams.
15. Illustrate how sodium sulfide (Na_2S) is formed.

A. Naming ionic compounds

In naming ionic compounds, the name of the cation is written first, followed by the name of the anion. Names of simple anions end with -ide. Generally, metals form cations and non-metals form anions. Ionic compounds are typically formed when metals combine with non-metals, for example, sodium chloride, calcium oxide, magnesium sulfide, etc. Some ions are formed by the combination of atoms of two or more elements, and are called **polyatomic ions**. Names of polyatomic ions generally do not end with -ide. Names, formulae and valencies of some common ions are given in Table 9.1.

Table 9.1: (a) Some common monoatomic ions

Name of ion	Formula	Valency
Sodium	Na^+	1
Lithium	Li^+	1
Potassium	K^+	1
Silver	Ag^+	1
Calcium	Ca^{2+}	2
Barium	Ba^{2+}	2
Iron (Ferrous)	Fe^{2+}	2
Iron (Ferric)	Fe^{3+}	3
Copper (Cuprous)	Cu^+	1
Copper (Cupric)	Cu^{2+}	2
Magnesium	Mg^{2+}	2
Zinc	Zn^{2+}	2
Aluminium	Al^{3+}	3
Fluoride	F^-	1
Chloride	Cl^-	1
Bromide	Br^-	1
Iodide	I^-	1
Oxide	O^{2-}	2
Sulfide	S^{2-}	2

Table 9.1: (b) Some common polyatomic ions

Name of ion	Formula	Valency
Hydroxide	OH^-	1
Nitrate	NO_3^-	1
Hydrogencarbonate	HCO_3^-	1
Carbonate	CO_3^{2-}	2
Sulfate	SO_4^{2-}	2
Ammonium	NH_4^+	1

9.5 Writing Chemical Formulae

You have learnt earlier how to write the formulae of compounds by finding the number of electrons which can be shared or transferred. There is yet another way to write the formulae quickly.

9.5.1 Writing chemical formulae of covalent compounds

Follow these steps to write the chemical formula of a covalent compound:

(i) Write the symbols of the constituent elements of the compound.
(ii) Write the valencies of these elements (refer to Table 9.1).
(iii) Crossover the valencies of the combining atoms and write them as subscripts after the symbols of elements, as shown below.

Examples

The formula of hydrogen chloride—

Symbol of element H Cl

Valency 1 1

The formula of the compound would be HCl.

If the valency is one after criss-crossing, it is not written.

The formula of hydrogen sulfide—

Symbol of element H S

Valency 1 2

The formula of the compound would be H_2S.

The formula of carbon tetrachloride—

Symbol of element C Cl

Valency 4 1

The formula of the compound would be CCl_4.

9.5.2 Writing chemical formulae of ionic compounds

Follow the steps given below to write the chemical formula of an ionic compound:

(i) Write the symbol of the cation first, followed by the symbol of the anion.

Note

The charges on the ions are not indicated in the formula of the compound.

(ii) Write the charges under the symbols rather than as superscripts.

(iii) Crossover the charges (only the numbers) as shown below to obtain the formula.

(iv) The chemical formula gives the simplest ratio of the elements in a compound. Therefore, after criss-crossing, the subscripts are divided by a common factor, if any. For example, if we get the subscripts 2 and 4, they are divided by 2 to get 1 and 2, which are then used as subscripts in the formula.

Examples

The formula of calcium chloride—

Symbol Ca Cl

Charge 2+ 1–

Formula $CaCl_2$

Thus, in calcium chloride, there are two chloride ions (Cl^-) for each calcium ion (Ca^{2+}). The positive and negative charges must balance each other, and the overall structure must be neutral.

The formula of aluminium oxide—

Symbol Al O

Charge 3+ 2–

Formula Al_2O_3

The formula for magnesium oxide—

Symbol Mg O

Charge 2+ 2–

Here, the valencies of the two elements are the same. We arrive at the formula Mg_2O_2 but it is simply written as MgO.

This method can also be used to write formulae of compounds of metals with other polyatomic ions, such as calcium carbonate.

For magnesium hydroxide, we write the symbol of the cation (Mg^{2+}) first, followed by the symbol of the anion (OH^-). Then, their charges (only the numbers) are criss-crossed to get the formula.

Examples

The formula for calcium carbonate—

Symbol Ca CO_3

Charge 2+ 2–

Formula $CaCO_3$

Here, the valencies of the two ions are the same. The formula $Ca_2(CO_3)_2$ is simply written as $CaCO_3$, as explained above.

The formula of magnesium hydroxide—

Symbol Mg OH

Charge 2+ 1–

Formula $Mg(OH)_2$

Thus, in magnesium hydroxide, there are two hydroxide ions (OH^-) for each magnesium ion (Mg^{2+}). We use brackets ( ) when we have two or more polyatomic ions of the same type in a formula. In the example of aluminium hydroxide given below, the bracket around OH with a subscript 3 indicates that there are three hydroxide (OH^-) ions bound to one aluminium ion. Brackets are not required when only one polyatomic anion is present.

Examples

The formula of aluminium hydroxide—

Symbol	Al	OH
Charge	3+	1–
Formula	$Al(OH)_3$	

Note: Formula of aluminium hydroxide is $Al(OH)_3$, not $AlOH_3$.

The formula of aluminium sulfate—

Symbol	Al	SO_4
Charge	3+	2–
Formula	$Al_2(SO_4)_3$	

Pause and Ponder

16. Name the following:
    (i) CO_2 ____________
    (ii) NO_2 ____________
    (iii) SF_6 ____________
    (iv) PCl_3 ____________
17. Write the formula for the following:
    (i) Sodium hydrogencarbonate ____________
    (ii) Sulfur dioxide ____________
    (iii) Ferric chloride ____________
    (iv) Cuprous oxide ____________
18. Write the formulae for the compounds formed from the following pairs of ions:
    (i) Fe^{3+} and OH^- (ii) K^+ and CO_3^{2-}

9.6 Properties of the Ionic and the Covalent Compounds

Activity 9.4: Let us experiment

1. Collect the samples of some compounds, such as camphor, sodium chloride, copper sulfate, sugar and naphthalene.

(A) Solubility in (i) water, (ii) kerosene, and (iii) petrol

2. Try dissolving each sample separately in the water, kerosene and petrol.
3. Record your observations in Table 9.2.

(B) Electrical conductivity in the water

Safety first: Do not touch the electrodes when they are connected to the battery but use a low-voltage battery to avoid the risk of shock. Petrol and kerosene are flammable liquids, so be careful while working with them.

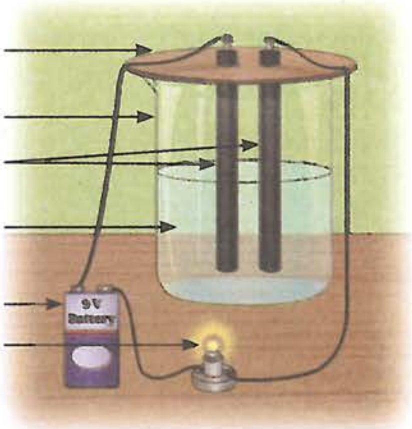


Fig. 9.15: Experimental set-up for electrical conductivity of a solution

4. Take two carbon or metal electrodes and insert them into a piece of cardboard by drilling two holes.
5. Connect one end of each electrode to the terminals of the 9 V battery and to the light bulb.
6. Test the electrical conductivity of each solid sample and observe whether the bulb glows. Record your observations.
7. Test the electrical conductivity of each sample dissolved in water by transferring the solution to the beaker one at a time and observing whether the bulb glows (Fig. 9.15).
8. Record your observations with other samples given in Table 9.2.

Table 9.2: Solubility and electrical conductivity observations

Compound	Experiments				
	Solubility in			Electrical conductivity of compounds in	
	water	kerosene	petrol	solid state	water
Camphor					
Sodium chloride					
Copper sulfate					
Sugar					
Naphthalene					
Any other					

9. Group the compounds showing similar properties listed in Table 9.2.


(a) Sodium chloride

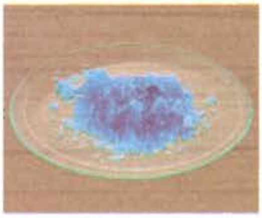

(b) Copper sulfate

Fig. 9.16: Ionic compounds

Ionic compounds like sodium chloride (Fig. 9.16a) and copper sulfate (Fig. 9.16b) are generally soluble in water but insoluble in solvents, such as kerosene and petrol. In contrast, most covalent compounds, such as camphor (Fig. 9.17a) and naphthalene (Fig. 9.17b) are insoluble in water but dissolve in kerosene and petrol.

Ionic compounds do not conduct electricity in the solid state because their ions are held in fixed positions by strong forces. To conduct electricity, ions must be free to move, which occurs only when the ionic compounds, such as sodium chloride and copper sulfate, are dissolved in water. On the other hand, some covalent compounds, such as sugar, are soluble in water but do not provide ions in solution; therefore, they do not conduct electricity. Other covalent compounds, such as camphor and naphthalene, also do not conduct electricity. Can you give a reason?

Predict whether ionic and covalent compounds would conduct electricity in the molten state (the melted state of a substance).

Ionic compounds generally have high melting and boiling points due to strong inter-ionic attractions, whereas covalent compounds usually have low melting and boiling points.

Pause and Ponder

19. What type of chemical bond is present in a solid compound that does not conduct electricity in the solid state but conducts electricity when dissolved in water?
20. Metal M, with two electrons in its valence shell (M shell), reacts with oxygen to form a compound that is slightly soluble in water. Predict its:
    (i) formula
    (ii) type of bond
    (iii) electrical conductivity of its aqueous solution.

9.7 Molecular Mass of Covalent Compounds

Since you know the formulae of the covalent compounds, you can find the masses of their molecules by simply adding up the masses of the atoms present in them.

(a) Camphor

(b) Naphthalene

Fig. 9.17: Covalent compounds

Example 9.4

Molecular mass of water (H_2O)

Atomic mass — H = 1 u; O = 16 u

Molecular mass of H_2O = (1 u × 2) + (16 u × 1) = 18 u

Example 9.5

Molecular mass of carbon dioxide (CO_2)

Atomic mass — C = 12 u; O = 16 u

Molecular Mass of CO_2 = (12 u × 1) + (16 u × 2) = 44 u

You have learnt in section 9.4.2 that in ionic compounds, the ions form 3-D crystals, i.e., ionic compounds do not form molecules.

Pause and Ponder

21. Find the molecular mass of nitric acid (HNO_3).
    Atomic mass — H = 1 u; N = 14 u; O = 16 u.
22. Find the molecular mass of methane (CH_4).
    Atomic mass — C = 12 u; H = 1 u.

9.8 Formula Unit Mass of Ionic Compounds

In ionic compounds, the collection of the simplest whole number ratio of ions is termed as a **formula unit**. The mass of a formula unit is called the **formula unit mass**.

Example 9.6

Formula unit mass of sodium oxide (Na_2O)

Atomic mass — Na = 23 u; O = 16 u

Formula unit mass of Na_2O = (23 u × 2) + (16 u × 1) = 62 u

Example 9.7

Formula unit mass of calcium nitrate, $Ca(NO_3)_2$

Atomic mass — Ca = 40 u; N = 14 u; O = 16 u

Formula unit mass of $Ca(NO_3)_2$ = (40 u × 1) + {(14 u × 1) + (16 u × 3)} × 2

= 164 u

Pause and Ponder

23. Find the formula unit mass of potassium chloride (KCl).
    Atomic mass — K = 39 u; Cl = 35.5 u.
24. Find the formula unit mass of magnesium hydroxide, $Mg(OH)_2$.
    Atomic mass — Mg = 24 u; O = 16 u; H = 1 u.

Understanding atoms, molecules and chemical bonding reveals the hidden science behind everything we use and consume each day. It shows how tiny atoms combine to build the universe we live in!

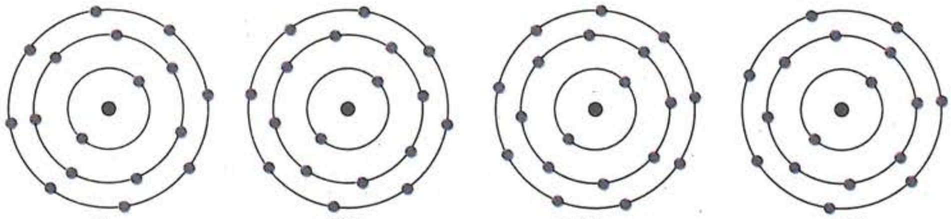
At a Glance

- Mass can neither be created nor destroyed in a chemical reaction. This is known as the Law of Conservation of Mass.
- A compound always contains the same elements combined in a fixed ratio by mass, no matter how it is formed or from where it is obtained. This is called the Law of Definite Proportions.
- A molecule is defined as an electrically neutral entity consisting of more than one atom that can exist independently and shows all its chemical properties.
- Atoms combine to form molecules of elements or compounds to become stable. Atoms are held together by a force called a chemical bond.
- A covalent bond is formed by the sharing of electrons between atoms.
- An ionic bond is formed by the transfer of electrons between atoms, where one atom loses electrons and the other gains electrons to form cations and anions, respectively.
- The chemical formula of a covalent compound represents the elements and number of atoms of each element present in it.
- The chemical formula of an ionic compound represents the simplest whole number ratio of atoms of different elements present in it.
- Molecular mass is the total mass of a molecule, calculated by adding the atomic masses of all the atoms constituting it.
- Formula unit mass of an ionic compound is the sum of the atomic masses of all the atoms present in a formula unit (simplest whole number ratio of ions in an ionic compound).

Revise, Reflect, Refine

1. A particular element (A) has one electron in its third shell. There is another element (B) with six electrons in its second shell.
   (i) How many electrons does A tend to give or take to become stable?
   (ii) What kind of ion would it form?
   (iii) How many electrons does B tend to give or take to become stable?
   (iv) What kind of ion would it form?
   (v) If A and B were to combine, what kind of bond would be formed?
   (vi) What would be the formula for the compound thus formed?
2. An element X has six electrons in its outer shell and forms a diatomic molecule.
   (i) Why would that be so?
   (ii) What kind of bond would it form?
   (iii) Draw the structure of the molecule it would form.
   (iv) A certain other element Y has two electrons in its second shell. Draw the structure of the molecule that X would form with Y.
3. You want to design a new ionic compound, where the total positive charge is 6+ and the total negative charge is 6 –. Which of the following combinations gives the correct number of ions?
   (i) 2 Al^{3+} and 3 Cl^{-}
   (ii) 3 Mg^{2+} and 1 PO_4^{3-}
   (iii) 2 Fe^{3+} and 3 O^{2-}
   (iv) 3 Ca^{2+} and 2 SO_4^{2-}
4. Choose the correct statement(s) and correct the false statement(s).
   (i) Elements are made up of molecules and compounds are made up of atoms.
   (ii) The molecule of a compound is always made up of two or more atoms of the same kind.
   (iii) One molecule of nitrogen gas contains three nitrogen atoms.
   (iv) Water is made of two hydrogen atoms, covalently bonded with one oxygen atom.
5. Write the chemical formulae for the following compounds.
   (i) Aluminium nitrate
   (ii) Calcium oxide
   (iii) Ferric oxide
6. Write the formulae of the compounds formed from the following pairs of ions.
   (i) Ca^{2+} and Br^{-}
   (ii) Al^{3+} and CO_3^{2-}
   (iii) K^{+} and SO_4^{2-}
   (iv) NH_4^{+} and Cl^{-}

7. Which of the following, in Fig. 9.18, correctly represents Cl^- ion (Atomic number of chlorine = 17).



(i) *(ii)* *(iii)* *(iv)*

Fig. 9.18

8. Determine the formula unit mass of the following substances.
   (i) Ammonium nitrate (NH_4NO_3), used as a nitrogen fertiliser, which is essential for plant growth.
   (ii) Phosphoric acid (H_3PO_4), used to make phosphate fertiliser and detergents.
   (iii) Sodium hydrogencarbonate ($NaHCO_3$), used to relieve acidity and helps in digestion.
9. Write the formulae for the compounds formed by the reaction of:
   (i) Magnesium and nitrogen
   (ii) Lithium and nitrogen
   (iii) Sodium and sulfur
   (iv) Aluminium and oxygen
10. Complete the Table 9.3 by writing the formulae of the compounds formed by the cations on the left and the anions at the top. $LiNO_3$ is given as an example.

Table 9.3

	NO_3^-	SO_4^{2-}	PO_4^{3-}
NH_4^+			
Li^+	$LiNO_3$		
Al^{3+}			
Cu^{2+}			

11. 5.3 g of sodium carbonate and 6.0 g of acetic acid react to produce 2.2 g of carbon dioxide, 0.9 g of water, and 8.2 g of sodium acetate. Verify whether the law of conservation of mass is valid.
12. If a species has 11 protons, 12 neutrons and 10 electrons then
   (i) what is its atomic number and mass number?
   (ii) is it neutral, a cation or an anion? Explain.
   (iii) write its electronic configuration.
   (iv) name the species.

13. Two elements, A and B, have the following configurations—

    A: 2, 8, 5   B: 2, 8, 7

    (i) Which element is more reactive?
    (ii) Will A and B form ionic or covalent bonds when they combine? Explain using electron transfer or sharing.
    (iii) Predict the formula of the compound they would form.

14. 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 molten state, while in solid state they can move freely.

    Choose the correct option:

    (i) Both A and R are true, and R is the correct explanation of A.
    (ii) Both A and R are true, but R is not the correct explanation of A.
    (iii) A is true, but R is false.
    (iv) A is false, but R is true.

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

The Journey Beyond

- Design and perform an experiment to show and compare that water always contains hydrogen and oxygen in the same ratio, regardless of its source.
- Compare atoms and ions of any three elements. Show the number of electrons before and after ion formation using bar graphs.
- Make a card game with cations and anions. Possible ideas may include—
  - Pick cards from the pile or from open cards and match them with cards in your hand to form compounds. You may discard any unwanted cards.
  - Ask other players for cards and form compounds using the cards they already have.
- To learn more about molecules you can explore the link given below—
  - https://phet.colorado.edu/sims/html/build-a-molecule/latest/build-a-molecule_all.html

The Quest Continues ...

Are there any chemical changes that do not obey the Law of Conservation of Mass?

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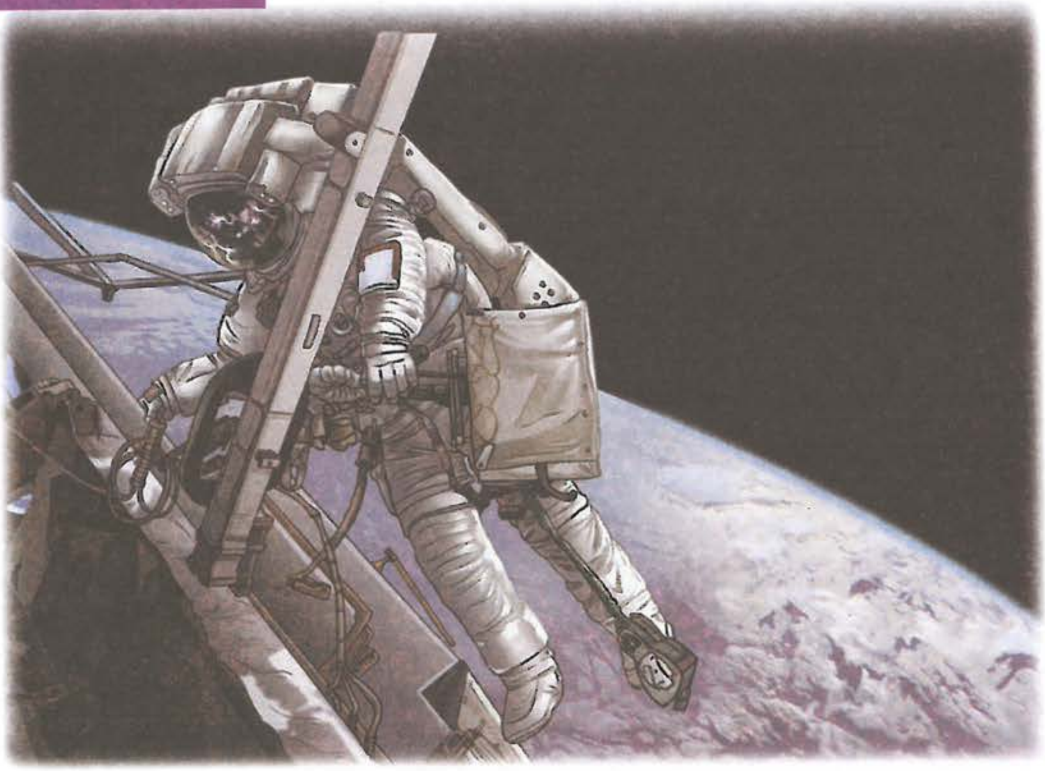
Chapter 10 Sound Waves: Characteristics and Applications



Think It Over

- Two astronauts are repairing the arm of a space station together during a spacewalk. Can they talk to each other and hear the sounds of metal clanking as they do on the Earth?
- How do most bats use sound to locate their prey in the dark at night?

Sound is an everyday sensory experience that helps us become aware of our surroundings. Every day, we hear a variety of sounds in our surroundings, such as human voices, birds chirping, waves crashing on the seashore, leaves rustling, mobile phones ringing, vehicles honking, music, and the claps of thunder. You have learnt in Chapter 7 that sound is a form of energy. You have also learnt that energy can neither be created nor be destroyed. It only changes from one form to another. Which form of energy gets converted to sound energy? How is sound produced and how does it reach our ears? In this chapter, we will try to find the answers to these questions.

10.1 Production of Sound

You learnt a few ways to produce sound in your textbooks for arts in the earlier grades.

Grade 3 *Bansuri* I Chapter 9 | Grade 4 *Bansuri* Chapter 13 | Grade 5 *Bansuri* Chapter 12 | Grade 6 *Kriti* I Chapter 7

Grade 7 *Curiosity* Chapter 4

Do you also remember learning about sonority earlier, a property of some metals where sound is produced when struck with an object (Fig. 10.1)?

Fig. 10.1: Taal a musical instrument

Activity 10.1: Let us explore

1. Take a cardboard box with one side open and a rubber band.
2. Stretch the rubber band across the open side of the box (Fig. 10.2).
3. Holding the box steady with one hand, pluck the rubber band with a finger. Do you hear any sound?
4. Pluck the rubber band again and watch it carefully. Is it vibrating?
5. Wait till the rubber band stops vibrating. Do you still hear the sound?
6. Change the tension in the rubber band by stretching it more or loosening it slightly and plucking it each time. Does the sound change? What changes do you **notice**?
7. Remove the rubber band from the box. Stretch it between two fingers and pluck it near your ear. Is the sound still produced? Is it as loud as before?

Fig. 10.2: Vibrating rubber band produces sound

You may have noticed that as long as the rubber band is stretched and vibrating, sound is produced. Once the vibration stops, so does the sound. From this activity, we **conclude** that sound is produced by vibrations. **Vibration** refers to the periodic to and fro motion (oscillations) of an object.

Pulling a stretched string or striking a metal object makes them vibrate, which produces sound. Likewise, when you blow through a *bansuri* (flute), vibration of the air inside the hollow pipe produces sound. You have learnt earlier that some of these methods are used in a variety of musical instruments. Sound can be produced by vibrating strings membranes, air columns, and many other vibrating objects. In most musical instruments, more than one vibrating part is involved in producing sound. The object that produces sound is called the 'source' of the sound.

Grade 4 Bansuri Chapter 13

Threads of Curiosity

How do humans and animals create sound? While talking or singing, gently touch your throat. Do you feel vibrations anywhere? In humans and some other animals, sound is produced by the vibration of vocal cords, which are tightly stretched muscular flaps located inside the voice box or larynx, in the throat (Fig. 10.3). The tongue, lips, mouth and nasal cavity in humans help in converting sound into speech or music.

Some animals produce sound by striking or rubbing certain body parts. For example, grasshoppers and crickets rub their wings or legs to produce sound.

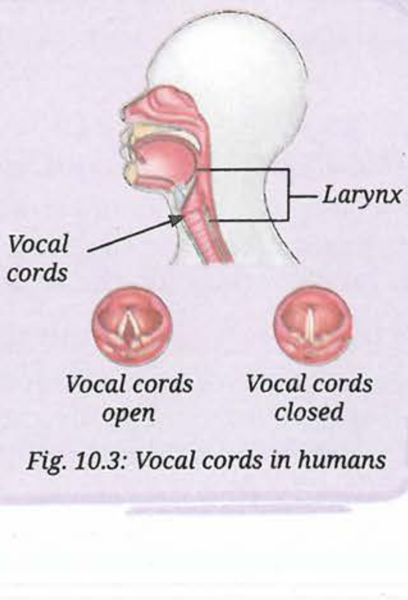


Fig. 10.3: Vocal cords in humans

10.1.1 Tuning fork

Fig. 10.4: (a) A tuning fork and a rubber pad

An instrument that is often used for experiments with sound is a tuning fork. A **tuning fork** is a U-shaped metal bar with a stem. It is usually made of steel or aluminium. The sides of the 'U' are called prongs or tines (Fig. 10.4a) which are struck on a pad to make them vibrate.

Activity 10.2: Let us explore

1. Take a tuning fork and a soft rubber pad.
2. Hold the tuning fork by its stem.
3. Strike one of the prongs of the tuning fork gently against the rubber pad (Fig. 10.4b) and bring it close to your ear. Do you hear a sound? (Take care not to strike the tuning fork against a hard surface).
4. Now, gently touch a water surface with one of the vibrating prongs of the tuning fork. Do you see waves forming on the surface of water?
5. Repeat step 3 a few times while bringing the prongs of the tuning fork near your ear in different orientations. Do you hear the sound?

Fig. 10.4: (b) Striking a tuning fork against a rubber pad

When you bring a vibrating tuning fork near your ear you hear the sound that is produced. When the prong touches the surface of water, waves form on the surface of water, indicating that the prongs of the tuning fork are indeed vibrating (Fig. 10.4c). These observations support the idea that sound is produced by vibrating objects.

Pause and Ponder

1. Explore various ways of producing sound.
2. Make a list of different types of musical instruments and **identify** their vibrating parts which produce sound.

Fig. 10.4: (c) A prong of vibrating tuning fork touching the surface of water

Threads of Curiosity

What if your name were a tune instead of a word? In Kongthong, a village near Shillong in Meghalaya also known as the Whistling Village every person has a 'tune name' that can be sung or whistled. This unique tradition, called *Jingrwai Iawbei*, begins at birth when a mother composes a lullaby-like tune for her child.

10.2 Propagation of Sound

You have seen that sound is produced by vibrating objects. How does sound reach your ear from the source? Sound travels through air but does it also travel through solids and liquids?

Activity 10.3: Let us investigate

1. You and your friend stand on opposite sides of a desk in the classroom. Let your friend gently knock or scratch on the desk. Listen carefully to the sound produced with your ear in the air.

2. Now, place your ear against the desk, close your other ear and listen again, as shown in Fig. 10.5. Are you able to hear the sound through the table?

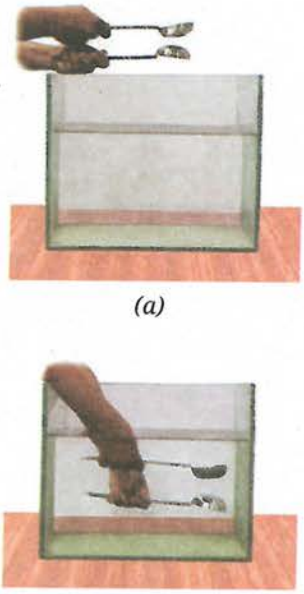
This shows that sound can also travel through solids.

Fig. 10.5: Investigating if sound travels through solid objects

Activity 10.4: Let us investigate

1. Take a large tub or bucket of water filled to the brim and two metal spoons.
2. Tap the spoons against one another and listen to the sound produced (Fig. 10.6a).
3. Now, submerge the two metal spoons in water without touching the sides or bottom of the bucket and tap them against one another again (Fig. 10.6b). Do you again hear the sound produced?

The sound of the submerged spoons tells you that the sound has reached you after travelling through water and air. If sound did not travel through liquids, would you have heard this sound?



(a)

(b)

Fig. 10.6: Tapping two spoons against each other in (a) air, and (b) water

Sound can travel or **propagate** through solids, liquids and gases. The material through which sound propagates is called a **medium**. Sound propagates from its source to you through a medium. But suppose that there is no medium in the space between you and the source of the sound. A space where there is no medium (matter) is referred to as **vacuum**. Would you hear sound in vacuum?

10.2.1 Sound needs a medium to propagate

A common experiment to show that sound needs a medium to propagate is the vacuum bell jar experiment shown in Fig. 10.7. An electric bell kept in a bell jar is switched on and the loudness of the sound is noted. As air is sucked out from the bell jar using a vacuum pump, the sound becomes fainter. Once a near vacuum is reached, almost no sound can be heard even though the bell can be seen ringing. When air is let back into the jar, the sound can be heard again and it gradually becomes as loud as before.

This experiment shows that sound cannot propagate in vacuum. Sound needs a medium to propagate. The medium can be a solid, a liquid, or a gas.

In outer space, there is a near vacuum, and thus, sound cannot propagate. Hence, astronauts in spacesuits doing spacewalks cannot directly hear each other speak or hear sounds like two metal objects clanking together. Instead, they communicate through special devices fitted into their spacesuits.

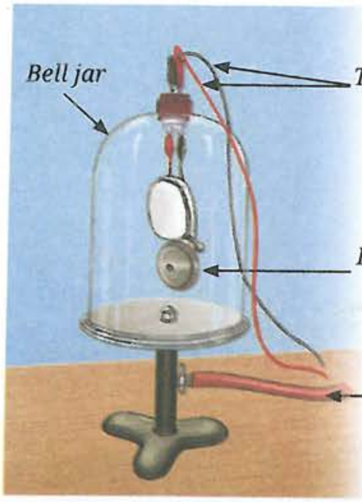


Fig. 10.7: Illustration of a vacuum bell jar

Pause and Ponder

3. Assertion (A): We cannot hear the sound of a bell ringing in a closed jar after most of the air is pumped out.

   Reason (R): Sound requires a medium to travel.

   Choose the correct statement:

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

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

   (iii) A is true, but R is false.

   (iv) A is false, but R is true.

10.3 Sound Waves

Sound needs a material medium to propagate but how does it propagate through that medium? In Activity 10.2, you could hear a sound when you held the vibrating tuning fork near your ear in different orientations. This indicates that sound propagates in multiple directions from a source (in this case from the tuning fork). In general, the directions in which sound propagates may depend on the shape of the source. However, for simplicity, we will consider and illustrate sound as moving in only one direction.

Let us begin with a simple activity using a slinky (a long, flexible metal or plastic spring toy) as an analogy for the medium through which sound travels. To simulate the production of sound, we will vibrate one end of the slinky.

Activity 10.5: Let us observe

1. Take a slinky and a marker.
2. Make a mark on a turn of the slinky with the marker. Lay out the slinky horizontally on a table or floor.
3. Ask a friend to hold one end of the slinky fixed while you hold the other end keeping the slinky slightly stretched.
4. Give the slinky at your end a sharp push towards your friend and then quickly pull it back again (Fig. 10.8). Do you **observe** a disturbance created in the slinky which moves towards your friend?
5. Now, push and pull the slinky end multiple times in quick succession (The pulling and pushing of the end of the slinky is similar to the sound being produced continuously). Are a series of disturbances produced in the slinky? Do these disturbances move across the length of slinky? Does the mark on the slinky move back and forth parallel to the direction of the disturbance?

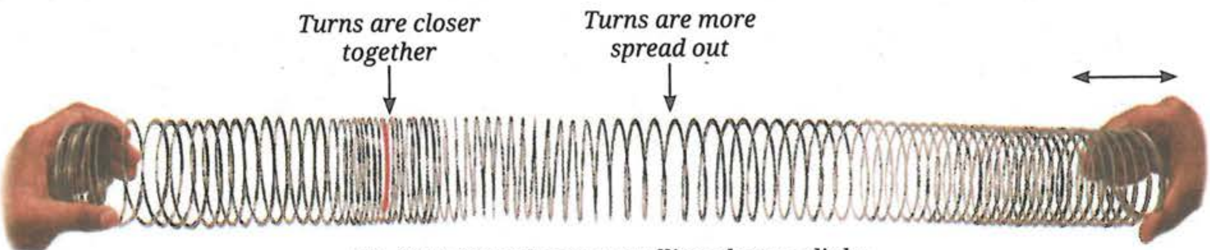


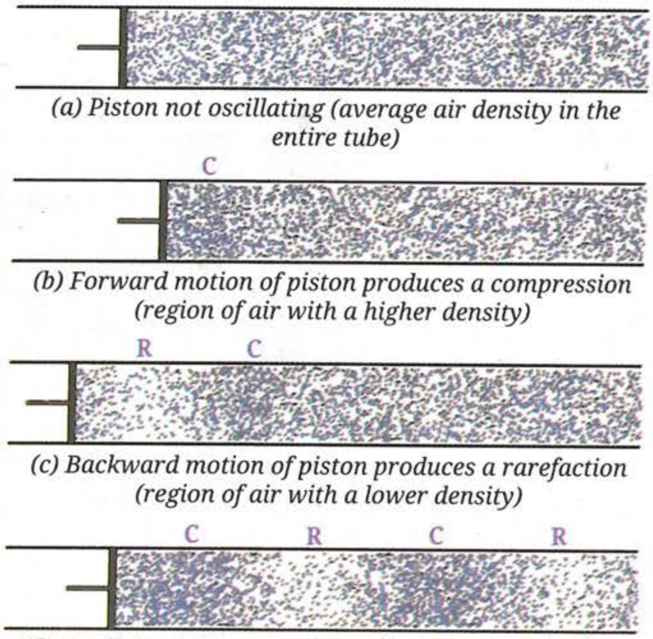
Fig. 10.8: Disturbance travelling along a slinky

You observe regions in the slinky where its turns are closer together than usual, and other regions where they are more spread out. These closely spaced and spread out regions appear to travel along the slinky. However, the mark does not travel along the slinky, it only oscillates about its position of rest parallel to the direction of the disturbance. Each turn oscillates about its own position while the disturbance travels from one end of the slinky to the other.

Sound moves in a similar way through a medium. In our analogy, the closeness or spreading out of the turns of the slinky represents the higher or lower density of air through which sound is travelling. Let us consider a long tube filled with air that has a piston at one end and is open at the other. The piston can be made to oscillate back and forth inside the tube. Here, the oscillating piston is used as a simple and idealistic model of the source of sound to help understand how sound travels through air.

When the piston is not oscillating, the air inside the tube has a certain uniform density, which we call the average density (Fig. 10.9a), where the dots represent the air particles. As the piston moves forward, it pushes and displaces the nearby air particles in a forward direction, thereby compressing the air and increasing its density in a small region close to the piston (Fig. 10.9b). This region of air with higher density (compared to the average density) is called a **compression** (C).

The compressed air particles collide with the particles further ahead passing the compression forward. The compressed particles further collide with their neighbouring particles, and so on. As a result, the higher density compression moves forward through the air even though the air particles themselves do not travel with it.



(a) Piston not oscillating (average air density in the entire tube)

(b) Forward motion of piston produces a compression (region of air with a higher density)

(c) Backward motion of piston produces a rarefaction (region of air with a lower density)

(d) Oscillating piston produces alternate compressions and rarefactions

Fig. 10.9: Density of air in a tube with a piston

As the piston moves backwards, the air particles move backwards in the direction of the piston and the air in a small region close to the piston becomes less dense (Fig. 10.9c). This region of air with lower density (compared to the average density) is called a **rarefaction** (R). Again, due to collisions with nearby particles, the rarefaction moves ahead while the particles themselves oscillate only about their mean positions.

As the piston oscillates in forward and backward directions, compressions and rarefactions are produced alternately (Fig. 10.9d). These travel away from the source, and a series of compression and rarefaction are produced.

The disturbance consisting of a series of alternating compressions and rarefactions propagating through a medium, without the actual flow of the particles of medium, is called a **sound wave**. The direction in which the wave travels is known as the **direction of propagation of the wave**.

Note

The particles of the medium do not travel with the wave. They just vibrate about their mean positions.

Ready to Go Beyond

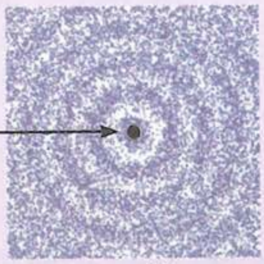


Fig. 10.10: Sound from a point source propagates in all directions as spherical waves

When the medium is not confined to a tube, its vibrating particles collide with the surrounding particles in all directions, and thus, the sound wave spreads out in all directions. A small sound source continuously producing sound in all directions causes compressions and rarefactions that spread through the surrounding medium in all directions as spherical waves (Fig. 10.10). When they reach the listener, they are perceived as sound.

Threads of Curiosity

What causes sudden loud sounds, such as when firecrackers explode or during a clap of thunder? These sounds are produced in a slightly different way. When air or gases are heated rapidly, they expand very rapidly in a short time. This rapid expansion creates a sudden disturbance in the air density that travels outward. When this disturbance reaches our ears, we perceive it as a loud sound pulse.

Fig. 10.11: A supersonic aircraft

A similar but more complex disturbance is produced when a supersonic aircraft (Fig. 10.11) flies at a speed higher than the speed of sound, creating a loud sound known as a sonic boom.

Did you notice (Fig. 10.9) that the displacement of the medium is parallel to the direction of wave propagation? In sound waves, the particles of the medium vibrate back and forth parallel to the direction of propagation of disturbance (Fig. 10.12). Such waves where the particles vibrate in a direction parallel to the direction of the wave propagation are known as **longitudinal waves**.

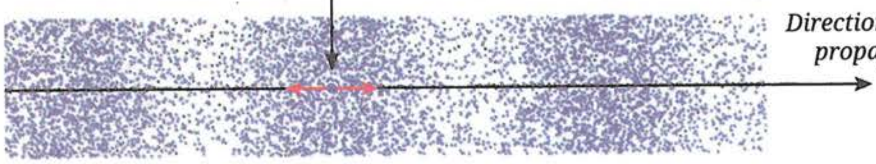


Fig. 10.12: A longitudinal wave

If there is no medium (i.e., no particles), is the propagation of sound waves possible? Without a material medium, sound waves cannot propagate. Waves that require a material medium for propagation are called **mechanical waves**. Sound wave is a type of a mechanical wave.

Ready to Go Beyond

Mechanical waves are of two types: longitudinal waves and transverse waves. Sound wave is an example of a longitudinal wave where the particles vibrate parallel to the direction of the wave propagation. In a transverse wave, the particles vibrate in a direction perpendicular to the direction of wave propagation (Fig. 10.13).

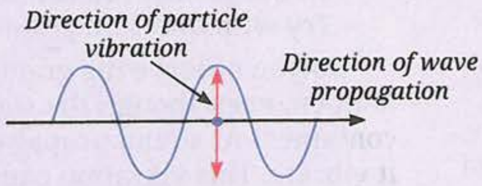


Fig. 10.13: Transverse Wave

Earthquakes produce seismic waves that travel through the Earth. These waves could be longitudinal or transverse. The longitudinal seismic waves are the first to be detected by seismographs that detect the earthquakes.

Not all waves are mechanical waves, i.e., not all waves need a medium to propagate. Light, which is a transverse wave, can travel through vacuum. This is why light from the Sun and other stars can reach the Earth. You will study waves in more detail in higher grades.

Next Level Up

Pause and Ponder

4. Assertion (A): Compressions and rarefactions move through the medium.

   Reason (R): Individual particles of the medium continuously move forward with the wave.

   Choose the correct statement:

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

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

   (iii) A is true, but R is false.

   (iv) A is false, but R is true.

10.4 Energy of Sound Waves

Activity 10.6: Let us experiment

1. Take a wide mouthed container, a cellophane or rubber sheet (such as that of a balloon) of size larger than its opening, a loud sound source (such as a metal plate and a beater) and some grains or particles (such as rice, semolina, salt, or chalk powder).
2. Stretch the sheet over the edges of the container tightly and fix it with tape or a rubber band (Fig. 10.14).
3. Sprinkle the grains evenly over the sheet, ensuring they are not clumped together.
4. Produce a loud sound near the bowl without touching it. Observe the grains on the sheet. Does the sound have any effect on the grains?

Fig. 10.14: Sound moving grains (coloured)

Note

In the propagation of a sound wave, it is the energy that is transferred, not the particles of the medium.

5. Repeat step 4 with different sources of sounds and observe the effect on the grains. You can try increasing or reducing the volume of sound. Try with different grains.

Do you observe the grains over the sheet move or jump? Why does this happen, even though the source of sound is not touching the sheet or the container? As sound propagates through air, it reaches the sheet and makes it vibrate. This vibration causes the grains to move.

This shows that sound is a form of energy. When the source of sound vibrates, it transfers energy to the surrounding medium. As sound waves propagate in a medium, the vibration of particles of the medium and their collisions with other particles result in the transfer of energy.

Ready to Go Beyond

Particles in a medium are never truly at rest. They are always randomly vibrating due to thermal energy. When a sound wave passes through the medium, it temporarily increases the vibration of these particles. After the wave passes, the particles return to their usual random motion.

Bridging Science and Society

Microphones (Fig. 10.15a) that help us capture sound from various sources convert sound energy to electrical energy. When we speak or sing into a microphone, the sound waves make a thin membrane, called a diaphragm, vibrate. These vibrations are converted into an electrical signal. A speaker (Fig. 10.15b) does the opposite; an electrical signal makes a cone or diaphragm attached inside the speaker vibrate, which produces sound. If all components work properly, the sound from the speaker closely matches the originally captured sound.

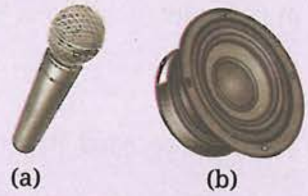


Fig. 10. 15: (a) A microphone, (b) a speaker

Pause and Ponder

5. When sound travels from a tuning fork to your ear, which of the following actually reaches your ear?
   (i) Air particles near the tuning fork
   (ii) Energy carried by sound waves
   (iii) The tuning fork material
   (iv) A continuous stream of compressed air

10.5 Graphical Representation of a Sound Wave

As a sound wave propagates, at any given instant of time the density of the medium varies periodically with distance from the source. Fig. 10.16a shows the periodic variation of density with distance at any given instant of time. The graph corresponding to it is shown in Fig. 10.16b where the distance is plotted on the x-axis, while the density of the medium is plotted on the y-axis. The average density is marked as a horizontal dashed line. The density varies (above and below the average density) with distance at a given instant of time.

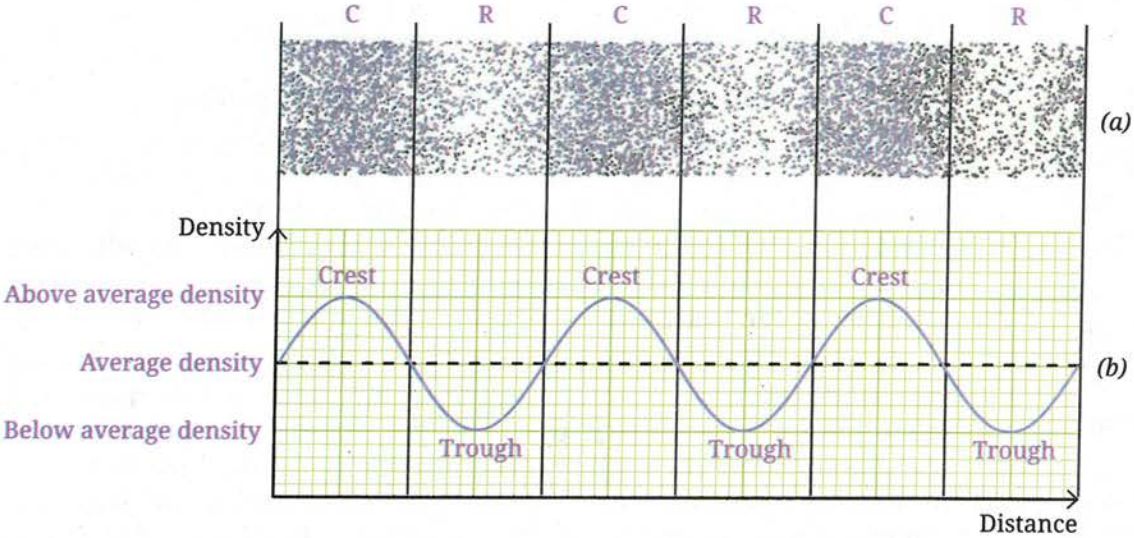


Fig. 10.16: For a sound wave (a) variation of density of medium, (b) graphical representation of variation of density with distance

In the region of a compression, the density of the medium increases above the average density and the highest point represents the maximum density (Fig. 10.16b). Thereafter, the density decreases and eventually falls below the average density in the region of rarefaction and the lowest point represents the minimum density. The highest point is called the **crest** and the lowest point is called the **trough** of the wave.

Ready to Go Beyond

Another way to make a graphical representation of a sound wave is to plot the variation of density of the medium with time, at a particular location in the medium.

Pause and Ponder

6. The variation of density of the medium for two sound waves is shown in Fig. 10.17 (a) and (b). **Label** compression and rarefaction by C and R on it. In the graph given in Fig. 10.17 (c) and (d), label the axes and **draw** the curves corresponding to Fig. 10.17 (a) and (b).

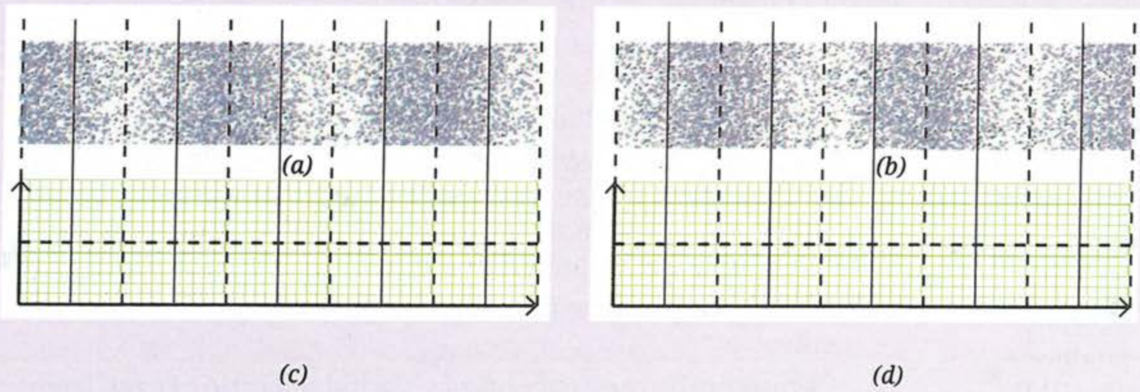
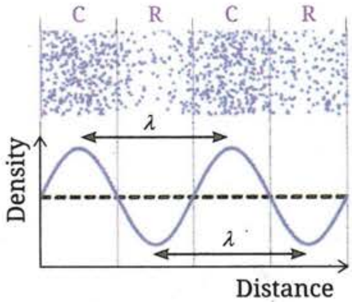


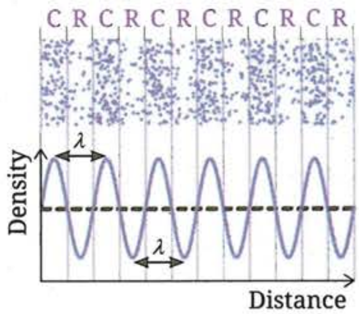
Fig. 10.17: Drawing graph to represent the variation of density of the medium for two sound waves

10.6 Characteristics of a Sound Wave

10.6.1 Wavelength, frequency and time period



(a) Long wavelength



(b) Short wavelength

Fig. 10.18: Sound waves

Let us learn about some quantities which are used to describe a sound wave. The distance between the two consecutive crests or two consecutive troughs is called the **wavelength** of a wave. This is shown in Fig. 10.18 where two sound waves are shown with long and short wavelengths. The wavelength is usually represented by λ (Greek letter **lambda**). Its SI unit is the **metre (m)**.

Another characteristic of sound wave is how often the density variations occur at a given position in the medium when a sound wave passes through that position. The density of the medium at the given position changes alternately between a maximum density (crest) and a minimum density (trough). The change in the density of the medium at a fixed point, from maximum to minimum and then again to maximum (or vice versa), makes one complete **oscillation**.

The number of density oscillations at a fixed point per unit time is the **frequency** of the sound wave. It is usually represented by ν (Greek letter **nu**). Its SI unit is per second ($\frac{1}{s}$ or s^{-1}) also called a **hertz** (symbol **Hz**).

The time taken for one complete density oscillation at a fixed point is defined as the **time period** of the wave. The time period of the wave is represented by the symbol T. Its SI unit is second (s).

The time period and frequency are inversely related; a shorter time period corresponds to a higher frequency.

$$\nu = \frac{1}{T} \qquad (10.1)$$

Usually, everyday sounds contain a mixture of many frequencies. Nearly single frequency sounds can be made by striking a tuning fork (Section 10.1.1) or by oral whistling.

Threads of Curiosity

There are some free apps which can be used by the teacher to produce as well as identify the sounds of different frequencies. Phyphox is one such app. In fact, using the 'Audio Scope' in the Phyphox app and whistling carefully will often produce a graph like Fig. 10.18 indicating that it is almost a single frequency sound.

Activity 10.7: Let us experiment (demonstration activity)

This activity is recommended to be performed as a classroom group activity facilitated by the teacher.

1. Use a mobile app, such as Phyphox that can identify frequencies of sounds. Use the 'Audio Spectrum' option that displays the frequency graphically or in hertz (Hz).
2. Try to sing the musical notes 'Sa, Re, Ga, Ma, Pa, Dha, Ni, Sa' one after another, or use a music or tone generating app on another phone to produce those notes. Observe how the frequency changes as each note is produced.
3. **Record** the approximate frequency values for each musical note.
4. **Compare** the musical notes by taking the ratio of each frequency with respect to the 'Sa'. Do you observe any pattern?
5. If both voice and mobile-generated notes are used, compare their frequencies for the same musical notes.

In this activity, you would have noticed that the frequency is lowest for the 'Sa' and gradually increases for the other notes. Each musical note has a distinct frequency, which makes it sound different. You can use the app to compare the frequencies of other sounds, including the voices of your friends too.

Example 10.1: If there are 10 density oscillations in 2 seconds at a given position, then **calculate** the (i) frequency of sound wave, and (ii) its time period.

Answer: Frequency of sound wave $= \frac{\text{number of oscillations}}{\text{time taken}} = \frac{10}{2\,\text{s}} = 5\,\text{Hz}$

Time taken for a single density oscillation at a position $= \frac{2\,\text{s}}{10} = 0.2\,\text{s}$

Pause and Ponder

7. Conduct Activity 10.1 once again with a thick rubber band and then with a thin rubber band. Does the thin rubber band vibrate faster than the thick rubber band? If yes, how do the frequency and time period of the sound produced by the thin rubber band differ from that of the thick rubber band?
8. If the frequency of a sound wave produced by an oscillating piston of a long tube filled with air is 20 Hz, then how many oscillations does the piston complete per minute?
9. For the sound wave represented by the graph shown in Fig. 10.19, what is half of its wavelength?

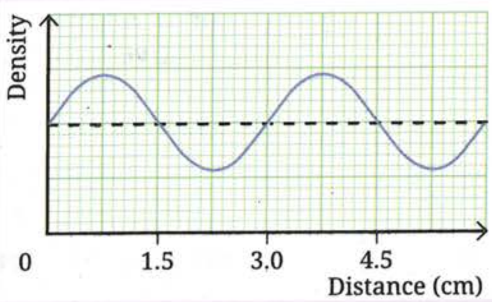
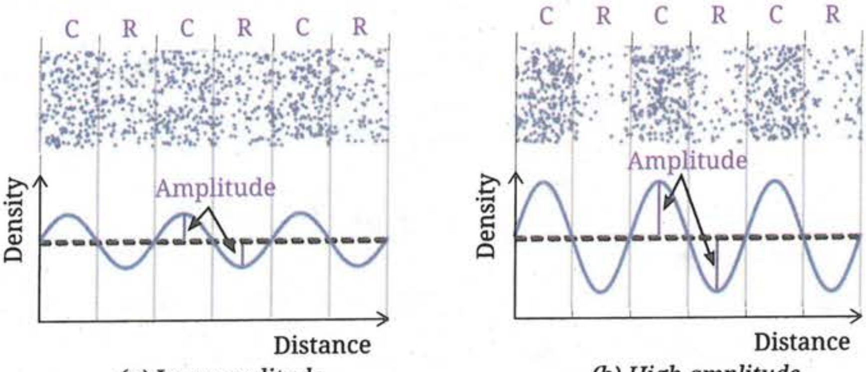


Fig. 10.19: Graphical representation of a sound wave

10.6.2 Amplitude and intensity of the sound waves

Sound propagates as density oscillations of the medium via compressions and rarefactions. The **amplitude** of a sound wave is the maximum change in the density of air in a compression (or a rarefaction) compared to the average density. A larger change in density corresponds to a larger amplitude (Fig. 10.20).



(a) Low amplitude *(b) High amplitude*

Fig. 10.20: Sound waves

The amplitude and the amount of energy a wave carries are related. A wave with a larger amplitude carries more energy than the one with a smaller amplitude. This can be seen in Activity 10.6. When the plate is struck harder, more energy is transferred to the particles of surrounding medium, causing larger displacements from their mean positions. As a result, the sheet vibrates to a larger displacement and the grains jump higher.

The amount of sound energy passing through a unit area perpendicular to the direction of the propagation of sound wave in a unit time is called the **intensity** of sound.

As sound wave travels away from its source, it spreads over a larger area (Fig. 10.21). Since the energy must be conserved, the same amount of energy is now spread over a larger area. Hence, the intensity decreases with distance from the source. Sounds produced with initial larger amplitude carry more energy and can travel a larger distance before intensity reduces to zero.

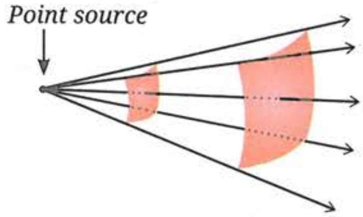


Fig. 10.21: Sound energy spreading over a larger area with distance

10.6.3 Speed of Sound

The speed of sound describes how fast sound waves propagate through a medium. In terms of compressions and rarefactions, one can think of speed as how fast these density disturbances propagate through the medium. The **speed of sound** can be defined as the distance which a point on a wave, such as a crest (or a trough), travels in unit time.

For a sound wave of given frequency, the distance between two consecutive crests (or two consecutive troughs) is one wavelength (λ). This distance is covered by the disturbance in one time period (T). Therefore, the speed of sound (v) is

$$\text{speed} = \frac{\text{distance}}{\text{time}} \quad \Rightarrow \quad v = \frac{\lambda}{T}$$

We know that frequency $\nu = \frac{1}{T}$ (Eq. 10.1). Thus,

$$v = \lambda \times \nu \qquad (10.2)$$

speed = wavelength × frequency

The speed of sound depends on the medium through which it travels. It travels fastest in solids, slower in liquids, and slowest in gases. For example, sound travels about 4 – 5 times faster in water and typically 15 – 20 times faster in solids than in the air.

The speed of sound in air also depends on the temperature and humidity. As we increase the temperature or humidity, the speed of sound increases. For example, the speed of sound in dry air is about 331 m s^{-1} at 0 °C and nearly 344 m s^{-1} at 22 °C.

What if ...

the speed of sound in air depended on its frequency? Would music still sound pleasant when a singer performs with instruments? Why or why not?

Ready to Go Beyond

In most media, such as air the speed of sound depends only on the medium and not the source or the frequency. If the frequency of the source changes, the wavelength of the sound wave in the medium changes, while the speed remains constant. Some special materials, such as porous foams or engineered structures can behave differently.

Example 10.2: Human hearing roughly spans 20 Hz to 20 kHz. What are the corresponding wavelengths in air for these two frequencies? Use the speed of sound in air as 344 m s^{-1}.

Answer: Using the relation between wavelength (λ), frequency (ν), and speed (v),

speed of the wave = frequency × wavelength

Therefore, wavelength $\lambda = \dfrac{\text{speed of the wave}}{\text{frequency}}$

(i) For ν = 20 Hz, $\lambda = \dfrac{344\ \text{m s}^{-1}}{20\ \text{s}^{-1}} = 17.2\ \text{m}$

(ii) For ν = 20 kHz = 20000 Hz, $\lambda = \dfrac{344\ \text{m s}^{-1}}{20000\ \text{s}^{-1}} = 0.0172\ \text{m} = 1.72\ \text{cm}$

The wavelength of sound in air corresponding to the frequency (i) 20 Hz is 17.2 m, and (ii) 20000 Hz is 1.72 cm.

Example 10.3: During a thunderstorm, lightning is seen before thunder is heard because sound travels much slower than light. If the time delay between seeing the lightning flash and hearing the thunder is measured to be 5 s, estimate the distance to the lightning strike. Use the speed of sound in air as 340 m s^{-1}. Assume that light (speed = 300000 km s^{-1}) reaches you almost instantaneously.

Answer: Distance = $v \times t$ = 340 m s^{-1} × 5 s = 1700 m

Lightning struck about 1.7 km away.

Example 10.4: From the graphical representation of a sound wave propagating in steel (Fig. 10.22), find its wavelength. Calculate its frequency and time period if the speed of sound in steel is 5000 m s^{-1}.

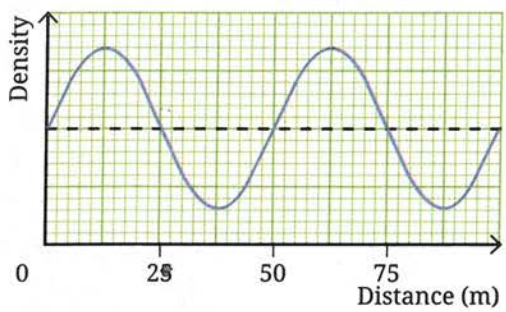


Fig. 10.22: Graphical representation of a sound wave

Answer: From graph (Fig. 10.22), the wavelength λ = 50 m

Using Eq. (10.2), the frequency of the sound wave is

$$\nu = \frac{v}{\lambda} = \frac{5000\ \text{m s}^{-1}}{50\ \text{m}} = 100\ \text{Hz}$$

Using Eq. (10.1), the time period of the sound wave is

$$T = \frac{1}{\nu} = \frac{1}{100\ \text{Hz}} = 0.01\ \text{s}$$

Pause and Ponder

10. Table 10.1 shows the speed of sound in a few media at atmospheric pressure.

Table 10.1: Speed of sound in different media at 15 °C

State	Substance/Medium	Approximate speed
Solid	Steel	5000 m s^{-1}
Liquid	Water	1500 m s^{-1}
Gas	Air	340 m s^{-1}

Compare the speeds in different media by finding the ratio of

(i) the speed of sound in water with respect to the speed in the air.

(ii) the speed of sound in steel with respect to the speed in the water.

11. Two friends are standing along a steel fence at a distance of 340 m from each other (Fig. 10.23). Gunjan places her ear over the fence and her friend knocks the fence with a metal object. Using the values of the speed of sound in steel and air given in Table 10.1, calculate the time difference between the sound that reached Gunjan through the air and the steel. Would it have been possible for her to distinguish between the two sounds? (The time interval between two sounds must be at least 0.1 s to be heard separately.)

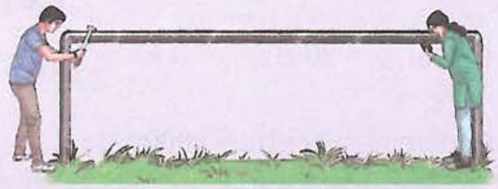


Fig. 10.23: Time difference between the sound reaching through air and steel

10.6.4 Human perception of sound

The physical properties of sound, such as time period, wavelength, frequency, amplitude and speed are well-defined and can be measured. However, how we experience sound is subjective. Human perception of sound is described by terms, such as loudness and pitch which do not have simple relations with the physical properties.

Pitch

How frequency is perceived by humans is called **pitch**. Sounds perceived to be shrill, such as a whistle or a siren are said to have high pitch, while deep sounds like thunder or an aircraft rumble have low pitch. In general, high pitch sounds have higher frequency and low pitch sounds have lower frequency, although the exact mathematical relation is complicated.

Threads of Curiosity

Everyone's voice sounds unique and you can often instantly recognise your teacher or friends calling out your name. Why do our voices sound different? Male, female, and children's voices differ not just in their frequency but also on how the sound is shaped by the throat, mouth, and nasal cavities. During adolescence, boys' vocal cords of boys lengthen and thicken, vibrating less frequently thus, 'deepening' their voice.

Let us carry out an activity to listen and appreciate sounds at different frequencies.

Activity 10.8: Let us experiment (demonstration activity)

This activity is recommended to be performed as a classroom group activity facilitated by teacher.

1. Open a mobile app that can generate sounds.
2. Set the frequency to 100 Hz, tap 'play', and listen carefully.
3. Increase the frequency in steps of 100 Hz up to 1000 Hz and describe how the sound changes.
4. Next, set the frequency to 50 Hz. Reduce the frequency till about 20 Hz or the point where you cannot hear the sound anymore.

Can humans hear all sounds? Humans can only hear a limited range of sound frequencies. The audible range or the human hearing range is from 20 Hz to 20,000 Hz (20 kHz). However, this range varies from person to person and decreases with age. Sound waves with frequency below 20 Hz are called **infrasonic waves**, while sound waves with frequency above 20 kHz are called **ultrasonic waves**. Humans cannot hear infrasound or ultrasound but some animals can. Dogs, cats, bats, dolphins can detect ultrasound, while elephants can detect infrasound.

Loudness

Humans perceive the amplitude of a sound wave as loudness. Sounds with larger amplitude are heard louder, while those with smaller amplitude sound softer. The loudness decreases as we move farther away from the source.

In everyday language, loudness and intensity are often used interchangeably. However, intensity is a measurable quantity, whereas loudness depends on the listener's hearing ability.

Bridging Science and Society

Sound loudness is commonly measured in decibels (dB). Very soft sounds like rustling leaves are around a few dB, normal conversation is about 60 dB, while very loud sounds, such as firecrackers can exceed 100 dB. Even a small increase in the dB level means a large increase in the sound intensity.

Unwanted or harmful sound is called noise. Noise pollution is a severe problem. Exposure to sound levels above recommended limits, especially for long durations can affect health, sleep, and hearing. Prolonged exposure to loud sound can lead to hearing loss, which can be tested using audiograms. People with hearing loss may use hearing aids, which consist of a microphone, amplifier, and speaker to help the wearer hear and communicate better.

Ready to Go Beyond

We often do not realise how amazing our sense of hearing is. When sound enters the ear, it causes a thin membrane called the eardrum to vibrate (Fig. 10.24). Tiny bones quickly amplify these vibrations and the cochlea converts them into electrical signals that rush to the brain, which perceives them as sound.

Having two ears allows the brain to pinpoint the direction of the origin of sound. By comparing which ear hears the sound first, it figures out where the sound came from based on the tiny time gap between the two (often less than a thousandth of a second).

Fig. 10.24: A schematic diagram of human ear

Animals hear in different ways. Snakes and fish sense vibrations through their bodies, while some insects have ear-like organs on their body parts.

Threads of Curiosity

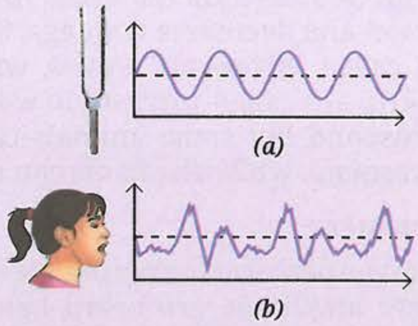


Fig. 10.25: Schematic representation of the sound produced by (a) a vibrating tuning fork or a person whistling, and (b) a child singing

A tone is a sound of a single frequency like that produced by a tuning fork or by oral whistling (Fig. 10.25a). A musical note like the sound produced by plucking a *tanpura* string or singing (Fig. 10.25b) is a combination of a lowest frequency called the fundamental and higher frequencies called overtones, which together create a rich and pleasant sound. Indian string instruments like the *sarangi*, *sitar*, and *veena* often use extra strings to enrich this combination.

Even when different instruments like a *flute*, *ektara*, or *tabla* play the same note at the same loudness each sounds unique. This quality is called timbre, and comes from their shape, material and construction, which determine the pattern and intensity of the overtones.

An octave is the interval between two notes where one has double the frequency of the other (for example, 200 Hz and 400 Hz), measured between their fundamental frequencies.

Meet a Scientist

Sir C. V. Raman won India's first Nobel Prize in Science for discovering the Raman Effect in light. He also made important contributions to acoustics by studying Indian percussion instruments, such as the *tabla* and *mridangam* to understand how they produce rich and nuanced sounds.

Threads of Curiosity

Indian drums like the *tabla* (Fig. 10.26) or *mridangam* have a black patch at the centre of the drum head membrane called the *syaahi*. This patch alters the vibration of the membrane, allowing these instruments to produce a rich variety of sounds. The *syaahi* also gives a level of tonal control rarely found in other drums.


Fig. 10.26: A tabla set

10.7 Reflection of Sound

Grade 8 Curiosity Chapter 10

Sound waves can bounce off obstacles like solids or liquids and this is known as the **reflection of sound**. Sound follow the same laws of reflection as those of light which you have learned earlier. The directions in which the sound is incident and is thereafter reflected make equal angles with the normal to the reflecting surface at the point of incidence, with all three lying in the same plane. One of the most common examples of the reflection of sound is an echo.

10.7.1 Echo

If we shout near a mountain, a cliff, or in a long corridor we may hear our voice again after some time. This is known as an **echo**. The sound reflects off the hard surface of a distant object and comes back to us.

Echoes aren't heard everywhere. In a small room, wall reflections arrive too quickly for the brain to separate them from the original sound. If the time gap between two sounds reaching us is at least 0.1 s, we can hear them as separate sounds. If it is less than 0.1 s, then we cannot clearly distinguish between them. This time duration of 0.1 s can help us estimate the minimum distance of a reflecting surface from which we can hear an echo.

If we take the speed of sound as 340 m s^{-1}, the distance travelled by sound in 0.1 s is

$$\text{distance} = \text{speed} \times \text{time} = 340 \text{ m s}^{-1} \times 0.1 \text{ s} = 34.0 \text{ m}$$

Note that 34 m would be the distance travelled by sound from the source to the reflecting surface and back. Hence, the minimum echo distance is half of this or 17 m.

Echoes are stronger from hard and smooth surfaces that reflect sound. Soft surfaces like curtains tend to absorb sound, while rough surfaces scatter it in different directions, and in such cases it is not possible to hear the echoes clearly.

Example 10.5: You clap in an empty corridor and hear an echo after 0.5 s. If the speed of sound in air is 340 m s^{-1}, calculate your distance from the wall.

Answer: Sound travels to the wall and back, thus,

$$\text{distance from wall} = \frac{v \times t}{2} = \frac{340 \text{ m s}^{-1} \times 0.5 \text{ s}}{2} = 85 \text{ m}$$

Pause and Ponder

12. An experiment is being set up that requires echoes to arrive at least 0.2 s after the emission of sound. What minimum distance should a reflecting surface be placed at? Assume the speed of sound to be 343 m s^{-1}.

10.7.2 Reverberation

Sometimes the emitted sound can undergo multiple reflections from the walls in a large hall or auditorium. Multiple reflections make sound persist after the source stops emitting sound, a phenomenon called **reverberation**. This occurs when sound reflections from surfaces arrive with a time difference less than 0.05 s.

Modern auditoriums and large concert halls are architecturally designed to have desirable reverberations, which allow the audience everywhere to hear speech, music, and other sounds clearly without any distortions. Sound absorbing panels, upholstered chairs, curtains and other soft, porous surfaces reduce reverberations by unwanted sources otherwise it could lead to a garbled sound.

Threads of Curiosity

Medieval architects across the world, including in India, designed several monuments with deep acoustic insights. The renowned Whispering Gallery of the *Gol Gumbaz* in Bijapur, Karnataka, has a remarkable design that allows even a faint whisper to be heard multiple times across the large dome.

10.8 Ultrasonic and Infrasonic Waves, and their Applications

Sound waves with frequencies outside the human audible range have important applications in science, medicine, and technology.

Threads of Curiosity

- Sound waves
  - Infrasonic waves (less than 20 Hz)
    - Used for detecting natural events, such as earthquakes and volcanic eruptions
    - Used for detecting severe storms as such waves travel long distances through air and the Earth
  - Human audible range (20 Hz to 20 kHz)
  - Ultrasonic waves (more than 20 kHz)
    - Used for imaging internal organs without surgery (known as ultrasonography)
    - Used for breaking kidney stones into smaller pieces, which can then be passed out of the body
    - Used for ultrasonic welding and for cleaning delicate machine parts in industries
    - Used for detecting defects inside metal blocks during construction and industrial testing
    - Used for locating objects when sound waves get reflected off them

10.8.1 Echolocation

Bats are nocturnal creatures that fly and search for their prey in the dark without colliding into objects. Most bats emit short bursts of ultrasonic waves which are reflected from nearby objects. By sensing the echoes the bat can determine the position of obstacles and prey (Fig. 10.27).

This ability to locate objects using reflected sound waves is called **echolocation**. Besides bats, animals such as dolphins, whales, and some birds also use echolocation for navigation and hunting.

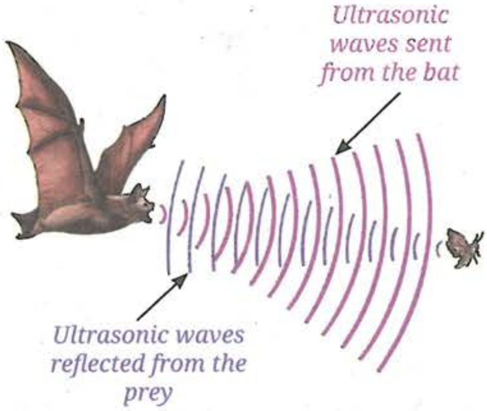


Fig. 10.27: Echolocation by bats

What if ...

humans could detect ultrasonic waves like dogs can? What would be the advantages and disadvantages?

Humans have adapted the same principle in underwater exploration through sonar (sound navigation and ranging). In sonar, ultrasonic waves are sent into water and the reflected waves are analysed to determine the distance, direction, and speed of underwater objects, such as submarines or shipwrecks (Fig. 10.28).

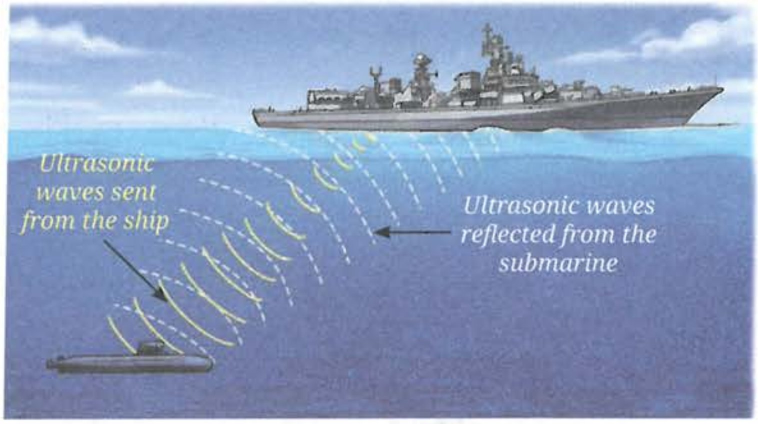


Fig. 10.28: Functioning of sonar

Example 10.6: A naval sonar signal sent into seawater returns after 0.90 s. The speed of sound in seawater is 1530 m s^{-1}. How far is the object?

Answer: Time taken for the signal to reach the object and travel back = 0.90 s

Time taken to reach the object is half of above time $= \frac{0.90\text{ s}}{2} = 0.45\text{ s}$

Thus, distance = speed × time = 1530 m s^{-1} × 0.45 s = 688.5 m

Bridging Science and Society

Drones (Fig. 10.29) and aircrafts produce characteristic sound from their motors and engines. Even when they are hard to see, the low frequency humming they generate can be detected using sensitive sound sensors. This method, called audio surveillance, helps monitor airspace for safety and security.

Fig. 10.29: A drone

Pause and Ponder

13. Sound travels much farther in water than light, and thus, is used for various underwater applications. A sonar signal sent to find the depth of ocean takes 4 s to return. What is the depth of the ocean at that location if the speed of sound in seawater is 1500 m s^{-1}?

The Quest Continues ...

Sound helps us explore places and phenomenon beyond human hearing. Space probes have recorded the first sounds from Mars, scientists are timing the sound of distant earthquakes to measure tiny changes in ocean temperature to understand the Earth's changing climate, biologists are using the buzz of mosquitoes to identify disease-carrying mosquitoes, and researchers are listening to the tiny crackles produced by microbes in the soil to study soil health and biodiversity. As technology improves, sound is becoming an even more powerful tool to explore planets, living organisms, and the hidden activities of nature.

At a Glance

- Sound is produced by vibrating objects.
- Sound is a longitudinal mechanical wave that needs a medium to travel.
- Sound can propagate through solids, liquids and gases.
- In sound propagation, it is the density disturbance that travels and not the particles of the medium. The particles of the medium only vibrate about their mean positions as the sound wave passes.
- The distance between the two consecutive crests or two consecutive troughs is called the wavelength of a wave.
- The change in density of the medium at a fixed point, from maximum to minimum, and then again to the maximum (or vice versa), makes one complete oscillation.
- The number of density oscillations at a fixed point per unit time is the frequency of the sound wave.
- The time taken for one complete density oscillation at a fixed point is defined as the time period of the wave.
- The amplitude of a sound wave is the maximum change in air density in a compression (or a rarefaction) compared to the average density.
- The amount of sound energy passing through a unit area perpendicular to the direction of the propagation of sound wave in a unit time is called the intensity of sound.
- The speed of sound can be defined as the distance which a point on a wave, such as a crest (or a trough), travels in unit time.
- Echoes and reverberations are heard because of the reflection of sound from various surfaces.
- Sound waves with frequency below 20 Hz are called infrasonic waves. Sound waves with frequency above 20 kHz are called ultrasonic waves.

Revise, Reflect, Refine

1. Which observation best supports the idea that sound is a mechanical wave?
   (i) Sound shows reflection
   (ii) Sound needs a medium to propagate
   (iii) Sound has frequency
   (iv) Sound carries energy
2. For a sound wave propagating in a medium, increasing its frequency will increase its
   (i) wavelength
   (ii) speed
   (iii) number of compressions per second
   (iv) time period

3. If 20 compressions pass a point in 4 seconds, the frequency is
   (i) 80 Hz
   (ii) 5 Hz
   (iii) 10 Hz
   (iv) 0.2 Hz
4. In a room, the reflected sound reaches the ear 0.05 s after its production. Will it produce an echo or reverberation? Justify your answer.
5. Graphs representing two sound waves are given in Fig. 10.30. If the scales on the X and Y axes of the two graphs are the same, which of the two sound waves has (i) greater wavelength, and (ii) smaller amplitude?

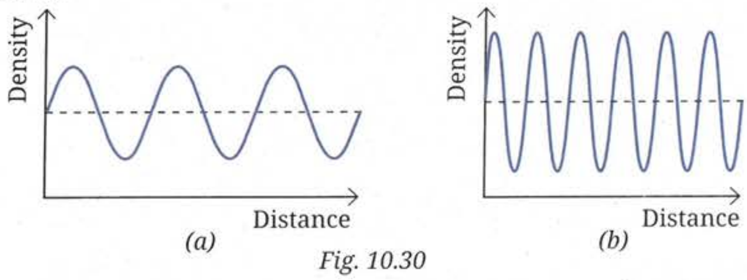


Fig. 10.30

6. The sound waves emitted by three sources A, B and C are represented in Fig. 10.31. If the frequency of A is maximum and C is minimum, identify the corresponding curves, and mark A, B and C on them.

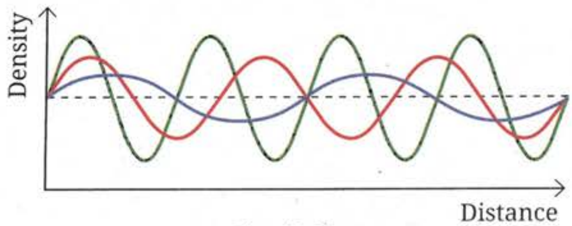


Fig. 10.31

7. Draw a graph to represent a sound wave for which the density amplitude is 3 units and wavelength is 4 cm.
8. In a movie, while showing the explosion of a spacecraft in space, a flash of light is shown along with sound at the same time. What are the errors in this depiction?
9. A source produces a sound wave of wavelength 3.44 m. If the wave travels with a speed of 344 m s^{-1} find its time period.
10. A ship searching for a sunken ship sent a sonar signal and detected an echo after 5 s. If ultrasonic wave travels at 1525 m s^{-1} in seawater, approximately how far down in the ocean is the wreckage of the sunken ship located?
11. A vehicle is fitted with an ultrasonic distance sensor as part of parking assistance system which provides echolocation, while the driver is reversing the vehicle. It emits ultrasonic wave (about 40 kHz) which is reflected by the obstacle. When the warning beep starts sounding at a distance of 1.2 m from the obstacle, how much time is taken by ultrasonic wave to travel to the obstacle and come back? Assume the speed of ultrasonic wave in air to be 345 m s^{-1}.

12. The speed of sound in air is about 331 m s^{-1} at 0 °C and nearly 344 m s^{-1} at 22 °C. Roughly how much extra time will the sound of thunder take to travel a distance of 1720 m, if the air temperature changes from 22 °C to 0 °C? Assume that all other conditions remain unchanged.
13. The variation of density of medium for a sound wave propagating with a speed of 340 m s^{-1} is shown in Fig. 10.32. Calculate the wavelength and frequency of the sound wave.

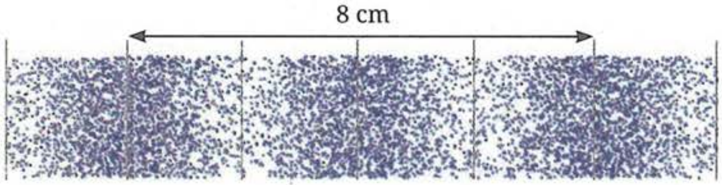


Fig. 10.32

14. The graphical representation of two sound waves A and B propagating at the same speed of 345 m s^{-1} is shown in Fig. 10.33. What is the wavelength of each of them? Also, calculate their frequencies.

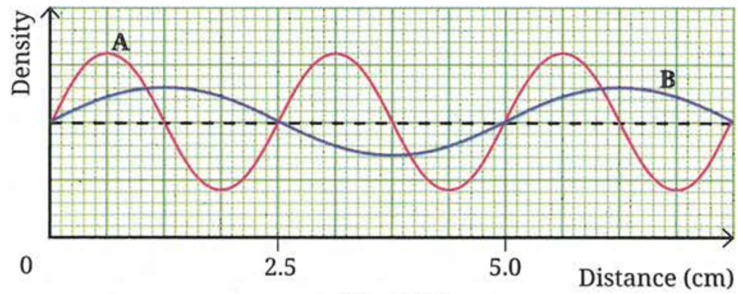


Fig. 10.33

15. Two identical sound sources are placed at A and B — one in air and one submerged in water (Fig. 10.34). Both produce sounds at the same time, which travel horizontally to the vertical side of the cliff and come back. If the time taken by the sound to return to A is 4.5 times than that of B, what is the ratio between the speeds of sound in air and water?

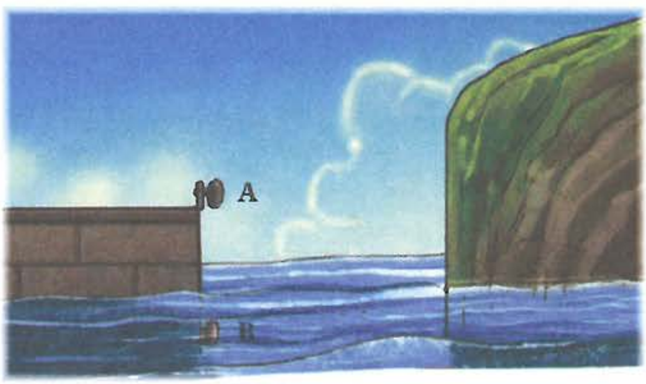


Fig. 10.34

The Journey Beyond

- Many people use earphones extensively these days. Find out the research studies that might have been done to understand the impact of excessive use of earphones on hearing (if any). Also, find out how hearing is tested and what are the decibel ranges for defining mild, moderate and severe hearing loss. What are the government schemes for purchasing or fitting of aids or appliances and free cochlear implants? Write an article on your findings.
- Make a cone using a poster paper or cardboard and adhesive tape. Cover a mobile phone that is playing music with the cone. Compare the loudness of the sound with and without the cone. You can also use another mobile phone with an app to measure the characteristics of the sound in both cases. Try experimenting with different shapes and record your observations. (This activity is to be facilitated by the teacher.)
- How does the curved design of ceilings and walls behind the stage in concert and conference halls improve the quality of sound for the audience compared to flat surfaces? You may consult an architect or search it on the internet.
- Carry out a simple activity to measure the speed of sound, along with a friend in a large open ground of size 200 m or more. (This activity is to be facilitated by the teacher.)
    - (i) Your friend stands at one end of the open ground with the balloons, while you stand at the other end with the stopwatch.
    - (ii) Signal your friend to burst one balloon. When you see the balloon burst, start the stopwatch. As soon as you hear the 'pop' sound of the bursting balloon, stop the timer and note down the reading.
    - (iii) Repeat this experiment multiple times and take the average value of the times noted.
    - (iv) Note the approximate distance between you and your friend using a map application on a mobile phone.
    - (v) Divide the distance measured with the average time to get the average speed of sound. What value of speed did you get from the experiment? Compare it with the speed of sound in air, which is typically about 346 m s^{-1} at 25 °C.
    - (vi) Why did you measure the time between 'seeing' and 'hearing' the balloon burst?
- Explore the internet resources to explore the effect of humidity and temperature on the speed of sound. Some such resources are:
    - (i) https://phet.colorado.edu/en/simulations/sound-waves/
    - (ii) https://musiclab.chromeexperiments.com/Experiments
    - (iii) https://phyphox.org/experiments

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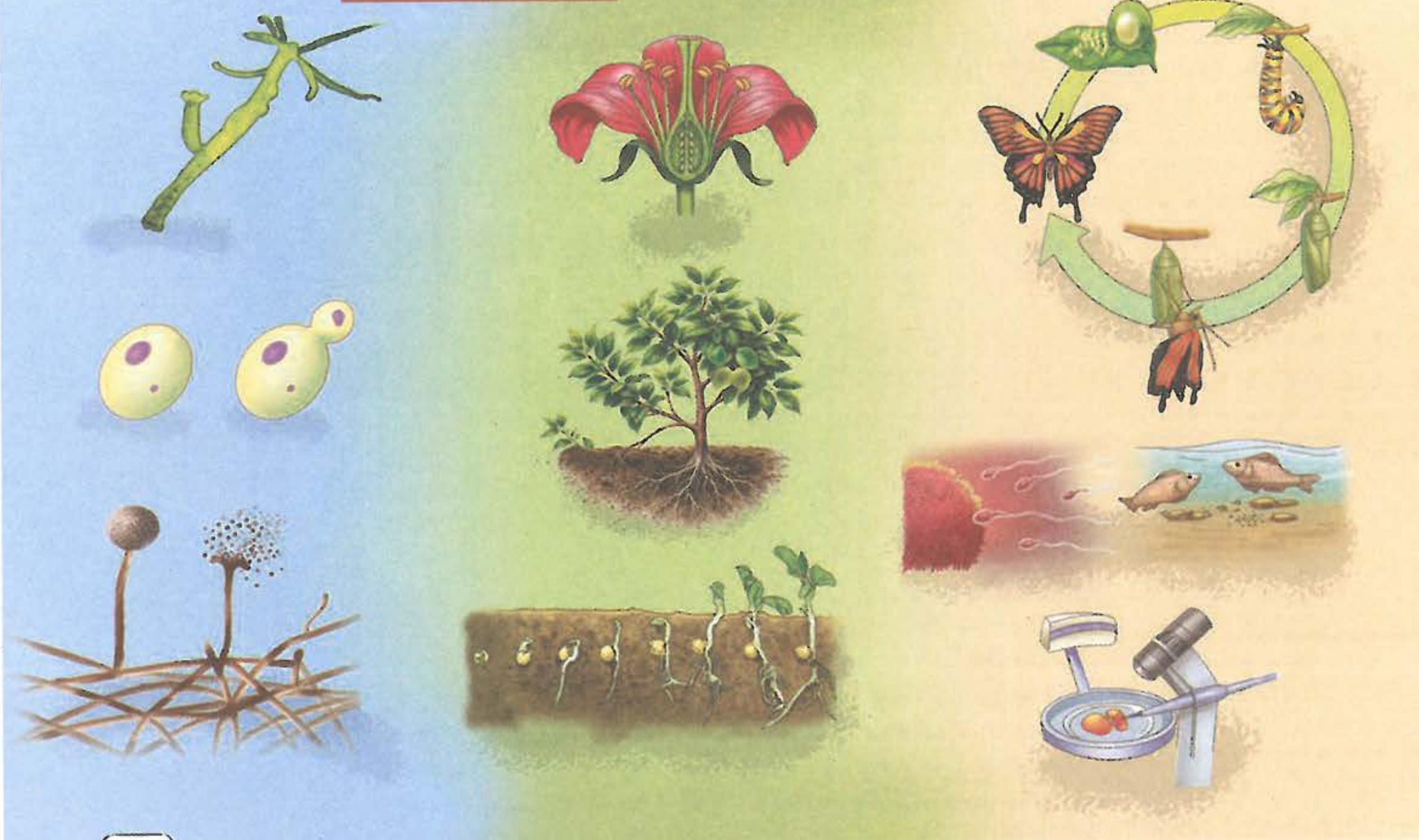
Chapter 11

Reproduction: How Life Continues



Think It Over

- When does a farmer prefer asexual or sexual methods of reproduction for crops production?
- Why do you think most complex animals and flowering plants use sexual reproduction, while many simple organisms, like yeast and hydra mainly reproduce asexually?

You have learnt that one of the important characteristics of living beings is that they reproduce. Every organism has a definite life span — it is born, grows, matures, reproduces and eventually dies. Reproduction is a biological process by which living beings produce new individuals of their own kind. This is how life on the Earth continues to exist. For example, a mango tree may grow old and die, but its seeds continue to grow as new mango plants. Similarly, cows give birth to calves, dogs to puppies, cats to kittens and humans to children.

Grade 8 Curiosity Chapter 13

You have also learnt that living beings reproduce in two main ways — asexually, where a single parent produces offspring that are almost exact copies of the parent and sexually, where offspring inherit a mix of characteristics from the two individuals. This mixing of characteristics may lead to the small differences between parents and their young ones. Accumulated over many generations, such differences help living beings adapt to changing environments, and sometimes even give rise to new kinds of species. In this chapter, we will explore how reproduction takes place in different organisms, including humans.

11.1 Asexual Reproduction

Asexual mode of reproduction is seen in many unicellular organisms like bacteria, amoeba, yeast and simple multicellular organisms (hydra, sponge). It is also seen in many plants. Recall the examples you studied in earlier grades.

Grade 8 Curiosity Chapter 13

Many types of plants sprout new shoots and roots from their existing parts. For example, plants with fleshy underground stems, such as potato and ginger, sprout new plants without producing seeds. Money plant stem, sugarcane stem cuttings grow into a new plant, *Bryophyllum* (Fig. 11.1) leaves sprout tiny plantlets which eventually grow into new plants. All these are examples of vegetative propagation, which means that new plants arise from the vegetative parts, i.e., from growing parts of a plant. The key point about this type of reproduction is that it involves only one parent and hence, produces genetically identical individuals.

Fig. 11.1: Bryophyllum leaf sprouts tiny plantlet

11.1.1 How is vegetative propagation in plants helpful in agriculture?

Asexual reproduction produces genetically identical individuals. This natural process has been adapted by scientists and horticulturists to develop several methods of vegetative propagation, such as cutting, grafting, layering and tissue culture for growing plants. These methods are widely used to efficiently propagate plants, and have significantly improved agricultural and horticultural practices. Such methods enable farmers to cultivate desirable crops on a large scale.

Activity 11.1: Let us explore

1. **Interact** with gardeners working in your school garden or farmers working in a field.
2. **Observe** the techniques of cutting, grafting and layering followed by them. Discuss these techniques with them and **record** your observations in your notebook.

Cutting

1. Note the following points while observing the technique of cutting in the field.
   (i) Does the gardener, scientist or horticulturist cut the overgrown branches of a plant at the end of its growing season? (Different plants have different growing seasons).
   (ii) Observe them prepare the cuttings from a plant for the purpose of growing new plants. Note the average length of the cuttings.
   (iii) Count the number of nodes and internodes on the cuttings.
2. Collect the cuttings of the shoots in the morning for planting.
3. Remove leaves from the lower half of each cutting.
4. Insert the cuttings up to approximately half of their length in the soil mixed with compost at an angle of about 45– 60° from the soil surface (Fig. 11.2).
5. Water them regularly and observe the change, if any.

Fig. 11.2: Cutting

Bridging Science and Society

Various Krishi Vigyan Kendras (KVKs) under the Indian Council of Agricultural Research (ICAR) allow farmers to gain vocational skills in modern grafting that help them grow high-yield fruits, and boost their income by learning various marketing strategies and government programmes.

Grafting

1. For grafting, take a healthy rooted plant (Plant A) (Fig. 11.3a) (for example, a wild rose variety) and a healthy stem piece from another plant (Plant B) of other varieties (for example, a yellow rose plant and/or a pink rose plant) (Fig. 11.3c and Fig. 11.3d).
2. Create a wound or a slit on a twig of Plant A (Fig. 11.3b).
3. Insert and fit the cutting of stem of Plant B into the slit of stem of Plant A (Fig. 11.3e).
4. Protect the wound or slit by using a cotton cloth or by wrapping film to avoid pests entering the graft until it heals (Fig. 11.3f). Cut the other branches of Plant A.
5. Water the plant regularly and observe the growth of Plant B along with Plant A.

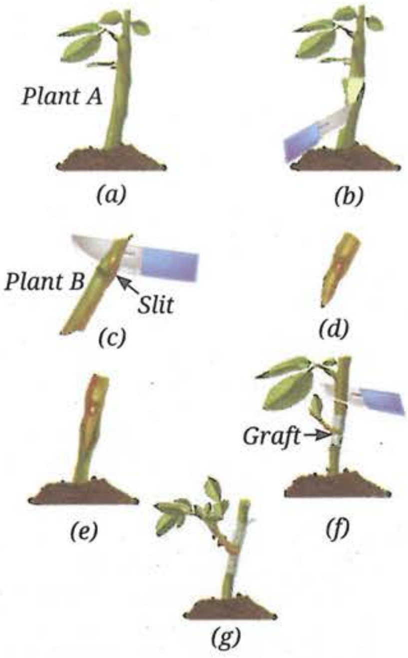


Fig. 11.3: Steps of grafting

Layering


Fig. 11.4: Layering

1. For layering, select a flexible, thin twig of a tree or a shrub, such as a lemon and bury the middle part of the twig under the soil surface (Fig. 11.4).
2. Water it regularly and observe the growth of new leaves on the twig buried in the soil.
3. After 10 – 15 days, the roots will develop from the area of the twig buried in the soil.
4. Once roots have developed, cut the twig from the parent plant, so that it can grow as a new plant.

These are some of the methods of asexual reproduction through which different varieties of plants can be propagated.

Bridging Science and Society

Propagation of plants by the tissue culture technique has revolutionised farming practices like in banana farming. Farmers are now provided mass-produced healthy plantlets from the shoot tip (apical meristem) of several plants, which help eliminate virus-infected plants and ensures high yields. This is also an example of asexual reproduction in plants.


Fig. 11.5: Plant tissue culture

You have learnt about various methods of vegetative propagation in plants. Let us examine asexual reproduction in other organisms.

Activity 11.2: Let us explore

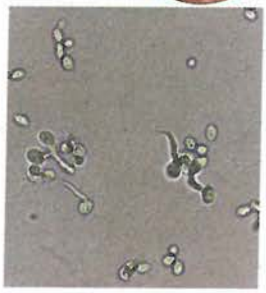


Fig. 11.6: Yeast with outgrowths

1. Take 20 mL of sugar solution (1 g in 10 mL) in a test tube.
2. Add a pinch of yeast granules to it and then place a cotton plug on the mouth of the test tube.
3. Keep it undisturbed in a warm place to allow the yeast to become active.
4. After 1 – 2 hours, place a small drop of the yeast mixture from the test tube onto a glass slide and mount it with a coverslip.
5. Observe the slide under a compound microscope at different magnifications and draw a diagram of what you observe.

Do you observe any small, round outgrowths (buds) emerging from the parent yeast cells as shown in Fig. 11.6? Do these features indicate that the yeast is duplicating? How do these observations help you in understanding reproduction in yeast?

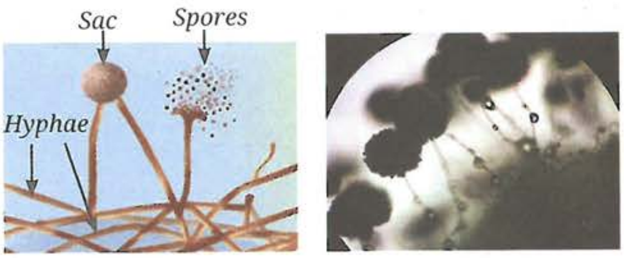
Fig. 11.7: Budding in hydra

In organisms, such as hydra (a multicellular animal), repeated cell division at a specific site on the parent body produces a small outgrowth called a **bud** (Fig. 11.7). The bud enlarges and separates from the parent to live independently. This process is called **budding**. In hydra, one can often see many buds growing on the parent's body at the same time.

Are there other methods of asexual reproduction in organisms? You have learnt that food like fruits get rotten by microbes (fungi). Where else do we find these microorganisms? You may have noticed that, if you leave cooked food on the kitchen counter for a day in warm weather, it starts to smell and may even grow fuzzy patches. Black patches are often seen on a damp wall. These are microorganisms. Where do these microorganisms come from? For long, people thought living things arose spontaneously from non-living matter. Experiments by Louis Pasteur proved that new life always comes from pre-existing life. He found the germ theory of disease, strengthened the cell theory (all cells arise from pre-existing cells), and led to practices like food and instrument sterilisation. We can explore how these microogranisms reproduce more closely by performing a simple activity that you can conduct at home or in school.

Activity 11.3: Let us experiment

1. Take a small slice of bread or a roti and lightly moisten it with a few drops of water.
2. Prepare a moist chamber using a plastic box or steel *dabba*. Place a thin layer of cotton in it, cover it with tissue paper and moisten it with pre-boiled water. Put the slice of bread or roti on the wet cotton bed covered with tissue paper.
3. Keep the moist chamber in a warm and dark place, away from direct sunlight (if the bread or roti starts drying, add a few drops of water to keep it moist).
4. Observe the bread or roti every day for any changes. Record your observations without touching it directly.
5. After three days, observe the surface of the bread or roti carefully using a magnifying glass. Do you notice the growth of mould?
6. When enough mould grows and spreads on it, carefully take the box to the school laboratory.



(a) Rhizopus (b) Aspergillus

Fig. 11.8: Fungi

7. With the help of a needle, carefully transfer a little mould onto a microscope slide. Under the guidance of your teacher, add cotton blue stain — a coloured dye to help see it better.
8. Observe the mould under the microscope and draw its diagram based on your observations.
9. **Compare** the diagram you have drawn with Fig. 11.8 and share your observations with your classmates.

Bridging Science and Society

Moulds on bread may look unpleasant but fungi benefit society greatly. Fungi grow very fast by spore formation and degrade organic wastes and pollutants. Fungi also play an important role in removal of heavy metals from industrial wastes. Many antibiotics are derived from fungi (penicillin and amoxicillin), saving countless lives from bacterial infections. Do you know any fungus that can degrade plastic?

Threads of Curiosity

We kept the moist chamber warm (25–35 °C) because spores of mould present in the air need warmth and moisture to grow on bread or roti. Lower temperatures slow or stop their reproduction. This is why, we refrigerate perishable food. Before refrigerators became common about 100 years ago, fresh food lasted only 1–2 days. Refrigeration (including deep freezing) revolutionised food habits, enabling year-round availability of fruits, vegetables, and dairy products, while preventing their spoilage from moulds and bacteria.

Do you observe thread-like structures with a round sac at the tip? Do you also see tiny round structure (spores) inside the sac? Where did the mould on your bread slice come from? It was not present when the bread was fresh. You may have observed fungi growing on rotten fruits or while preparing manure. In these cases, fungi grew due to spores present in the air. Similarly, in the case of bread, the mould grew from the spores already present in the air, which settled on the moist bread and began reproducing rapidly. Spores are formed in a sac-like structure (Fig. 11.8a) or on a swollen vesicle on a long strip of fungal hyphae (Fig. 11.8b).

Grade 8 Curiosity Chapter 2

Spores are produced in huge numbers (millions from one mould colony). Spores are lightweight, usually single-celled and float easily through air currents, waiting for moisture and nutrients to germinate quickly into a new individual.

In all the organisms studied so far in this chapter, the central process behind asexual reproduction is mitosis, a type of cell division that produces two daughter cells, each having the same number of chromosomes identical to the parent cell. Because of this, the offspring produced are genetically identical to the parent and are called **clones**. This method is fast and helps organisms increase their population quickly, especially when environmental conditions are favourable.

11.2 Sexual Reproduction

Sexual reproduction involves two parents in the formation of a new individual. This means both parents contribute to the genetic material of the offspring. However, if each generation were to receive the full set of chromosomes from both the parents, the chromosome number would double in every generation. This biological problem is solved by a special type of cell division known as meiosis.

11.2.1 How does meiosis help create variations in sexual reproduction?

Each species has a fixed number of chromosomes in their cells. Chromosomes are thread-like structures present in the nucleus of a cell and they carry genetic information. Humans have 23 pairs of chromosomes, that means, each pair consists of one chromosome each from two different individuals — with a total of 46 chromosomes.

Grade 8 Curiosity Chapter 13

Meiosis is a special type of cell division that forms gametes. In meiosis, the chromosome number of a parent cell (diploid) is reduced to half (haploid) in daughter cells. The resulting haploid cells are used only for reproduction and are called **gametes**. In animals, male gametes are called **sperm** and female gametes are called **eggs**. You have learnt about them already. In plants, the **pollen grain** contains male gametes and delivers them to an **ovule** which contains the female gametes (eggs). During meiosis, the chromosomes of each pair separate so that each gamete receives only one chromosome from each pair. This means that every human gamete has 23 chromosomes, each carrying genetic information for many characters. How many combinations of characters can gametes carry?

Activity 11.4: Let us explore

1. Take three pairs of beads of different colours (Fig. 11.9), each pair representing two contrasting characters on different chromatids of different chromosomes, such as:
   - Pair 1 (green): One light green bead and one dark green bead representing blonde and black hair colour, respectively on different chromatids of chromosome 1.
   - Pair 2 (blue): One light blue bead and one dark blue bead representing straight and curly hair, respectively on different chromatids of chromosome 2.
   - Pair 3 (red): One light red bead and one dark red bead representing brown and black eye colour, respectively on different chromatids of chromosome 3.
2. Make a combination from it by randomly picking one bead from each pair.
3. Write your combination as 'light green, light blue, light red'.
4. How many combinations can you make with just these three pairs of characters? Each time you make a combination using beads, you will get either the same combination or a different one. With just three pairs of characters, eight combinations are possible.
5. Imagine how many combinations are possible with 23 pairs of chromosomes, each carrying genetic information for many characters.

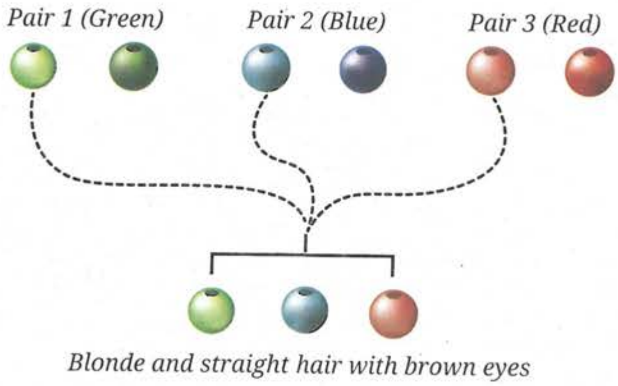


Fig. 11.9: Understanding the segregation of characters during the formation of gamete by meiosis

This random mixing provides many combinations, making children genetically different from their parents and also from their siblings. Each of us receives a unique combination of chromosomes. This creates variation among individuals, which is important for the survival of a species. Variation helps some individuals adapt better to changing environments and over time, this process contributes to evolution. For example, some people can tolerate low oxygen levels at high altitudes, or digest milk in their adulthood.

11.2.2 Sexual reproduction in flowering plants

Flowering plants, also called **angiosperms**, are the most diverse group of plants on the Earth. Flowers serve as reproductive organs in angiosperms, however, non-flowering plants like pines also reproduce sexually. You will study them in the next chapter.

Look at the herbs, shrubs and trees in your surroundings. Their leaves perform photosynthesis, their roots absorb water and nutrients from the soil, and their stems provide strength to the plant, these are some of the functions of a plant. Flowers also enhance the aesthetics of the plants as they are coloured and/or fragrant. How are these features of flowers useful for reproduction?

Explore flowers and their buds on some plants. Record your observations in your notebook. Do you observe thin, flat, green covering, and coloured projections present in both? In flower buds, the coloured projections are often covered by a green covering. In the bud stage, green covering around all the parts is the outermost whorl of the flower. This structure is called a **sepal**. Do you think that sepals protect flowers in the bud stage, along with other parts of the flower when it blooms? The coloured projections of flowers are called **petals** (Fig. 11.10). Do all flowers have these two parts? What are the other parts of a flower?

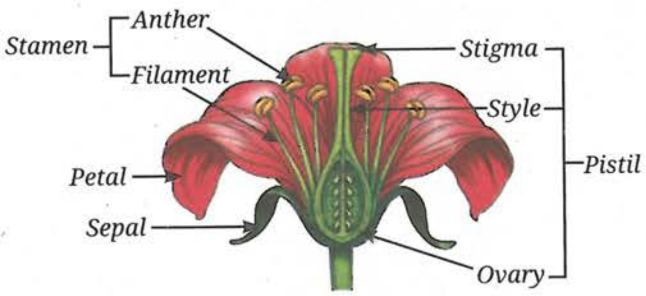


Fig. 11.10: Longitudinal section of a flower showing its different parts

Activity 11.5: Let us explore

1. Collect different types of flowers from your surroundings.
2. Carefully observe each part of the flowers you have collected, starting from the outer whorl to the inner one.
3. Record the presence of various floral parts in the different flowers that you collected in Table 11.1.

Table 11.1: Observation table to study the parts of a flower

S. No.	Flower parts	Presence of floral parts in different flowers				Other feature(s)	Guess the function of flower part
		A	B	C	D		
1.	Sepal	Yes					
2.	Petal	Yes					
3.	Stamen	No					
4.	Pistil	Yes					

4. **Analyse** the function of each part of the flower based on visible characters.
5. Cut a transverse and a longitudinal section of the ovary (swollen base of the pistil) and observe it under a dissecting microscope.
6. Record any other feature(s) in Table 11.1.
7. Draw a diagram of the structure you observed under the microscope.

A complete flower has four parts — sepals, petals, stamens and pistil. You might have noticed that in some flowers both sepals and petals are fused. Can you guess the function of the most attractive part of a flower — the coloured petals? The stamen is the male part (Fig. 11.10). It consists of a filament and an anther, which produces pollen grains containing male gametes. The pistil is the female part that has three subparts — stigma, style and ovary (Fig. 11.11). The stigma is located at the tip, and may be flat and/or sticky. The style is a thin long tube which connects the stigma to the ovary. The ovary contains ovules and each ovule has an egg cell (female gamete). You have learnt that the transfer of pollen from stamen to stigma is essential for the formation of fruits. How can you investigate it?

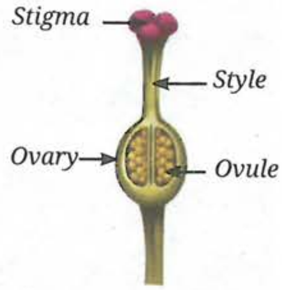


Fig. 11.11: Structure of a pistil

Activity 11.6: Let us investigate

1. **Identify** sweet pea (*matar*) or garden pea plants in a garden or a nearby field.
2. Select two juvenile (less developed) flower bud and three freshly blossomed flowers on the same pea plant.
3. Carefully remove the stamens from one of the two selected flowers buds and one of the three selected flowers.
4. Take muslin cloth bags and loosely wrap them around the flower bud, the flower bud of which stamens are removed, the flower of which stamens are removed and a freshly blossomed flower (Fig. 11.12).
5. Leave one freshly blossomed flower uncovered (without muslin cloth bag).
6. Observe them regularly and notice the development of fruits in place of the flowers that were not covered with muslin cloth. Allow them to grow for a few more days.
7. Once the pods are fully developed in the flowers without muslin cloth, remove the muslin cloth from all the wrapped flowers and observe them.
8. Note your observations in Table 11.2.

Grade 8 Curiosity Chapter 12


Fig. 11.12: Experimental set-up for pollination

Table 11.2: Observation table to study pollination in a pea plant

Treatments	Flower bud (wrapped with muslin cloth bag)	Flower bud with removed stamens (wrapped with muslin cloth bag)	Flower with removed stamens (wrapped with muslin cloth bag)	Flower (wrapped with muslin cloth bag)	Flower (without muslin cloth bag)
Fruit formation (Yes/No)					

In which treatment(s) do you find the flowers are replaced by fruits? What can we **infer** from this activity? You will notice that fruits are formed in place of flowers in all treatments except the one in which the stamens were removed from the flower bud. We can infer that the transfer of pollen grains from the anther to the stigma is necessary for fruit formation. The transfer of pollen grains from the anther to the stigma of a flower is called **pollination**.

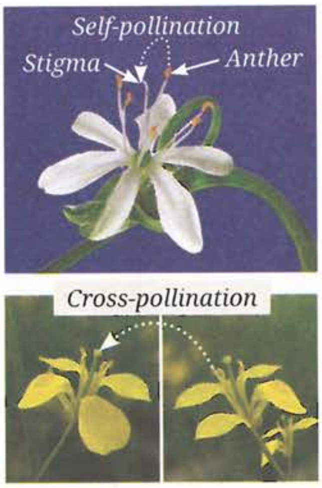


Fig. 11.13: Self and Cross-pollination

11.2.3 How does the process of pollination occur in flowers?

In the Activity 11.6, we stated that the process of pollination is the transfer of pollen to the stigma of a flower. The transfer of pollen occur to the stigma of the same flower or another flower of the same plant, is called **self-pollination** (Fig. 11.13).

If the pollen is transferred from the anther of a flower of one plant to the stigma of a flower of another plant of the same type, the pollination is called **cross-pollination** (Fig. 11.13).

The transfer of the pollen grains to the stigma is important for the formation of fruits and seeds. Nature has provided plants with various strategies for pollination to occur. What do you think will happen if pollination does not occur?

11.2.4 Pollination strategies and reproductive success

Pollination depends on external agents called **pollinators**, such as wind, water, insects (bees, butterflies), or birds. Pollination by wind is seen in plants like wheat, maize and rice, where pollen grains are light and small, produced in large numbers, and the stigma is long and feathery to trap them. In aquatic plants, such as *Vallisneria* and *Hydrilla*, pollination occurs through water, with currents carrying the pollen from one flower to another. Many plants, including sunflower, hibiscus and marigold are pollinated by insects, such as bees and butterflies. Their flowers are often brightly coloured, produce nectar, and give off fragrance to attract pollinators. The pollen grains are large, sticky or spiny, so they can attach to the insect's body and the stigma is also sticky to receive them. Some flowers like those of the coral tree and hibiscus plant, are pollinated by birds, such as Indian white-eye and sunbirds. Let us see how fruits and seeds are formed.

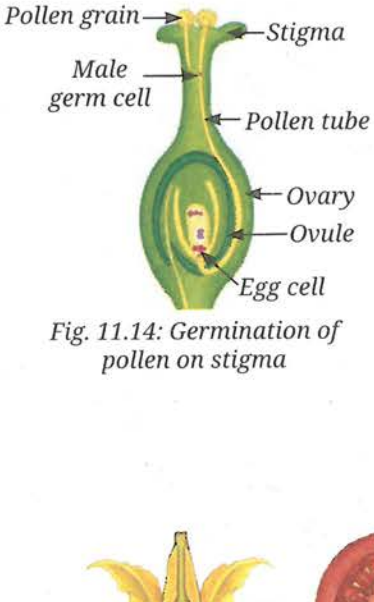


Fig. 11.14: Germination of pollen on stigma

11.2.5 Fertilisation and seed formation

Once the pollen reaches a compatible stigma, a remarkable process begins. Pollen grains produce pollen tubes that grow down through the style into the ovary. The male gamete moves through this tube and arrives at the ovule, where it fuses with the egg cell (Fig. 11.14). This fusion of gametes is referred to as **fertilisation** and it marks the beginning of a new life. The fertilised egg is called a **zygote**, which later develops into an embryo. In the meantime, the ovary surrounding the ovules enlarges and develops into a fruit, while the ovules develop into seeds inside it (Fig. 11.15). Seed dispersal takes place by wind or water and animals.


Fig. 11.15: Transformation of an ovary to a fruit

When conditions like water, air and temperature are favourable, the seed germinates and grows into a new plant. Thus, sexual reproduction not only produces new plants but also creates variation, helping plant species survive and adapt to their environment.

What is the approximate success rate of the common strategies — wind pollination and insect pollination — with respect to the seed formation?

Activity 11.7: Let us find out

Studies of pollen production and seed formation by two different pollination strategies in different flowers show the following approximate trends (Table 11.3) —

Table 11.3: Pollen production and seed formation data

Pollination strategy	Approximate pollen grains released per flower	Estimated average number of seeds formed
Wind-pollinated grasses (e.g., maize, wheat)	5,00,000–10,00,000	50–200
Insect-pollinated plants (e.g., sunflower)	20,000–40,000	800–1,000

1. Compare and analyse the two strategies in terms of (Table 11.3)—
   - Pollen to seed ratio
   - Efficiency of pollination and seed formation
2. Explain why producing a very large number of pollen grains can still be an effective pollination strategy.

Pause and Ponder

1. In a china-rose (hibiscus or *gudhal*) plant, a pollen tube grows and continues through the style after pollen lands on the stigma. Which process is about to happen next?
2. Look at the pictures (Fig. 11.16) of calotropis (madar) seeds and dandelion seeds given below. Can you guess what kind of seed dispersal these seeds are adapted for?
3. A farmer plants two varieties of maize side by side, but notices that seeds form only when pollen from one variety reaches the stigma of the other. What type of pollination is this?

(a) Madar seeds

(b) Dandelion seeds

Fig. 11.16

Meet a Scientist

P. Maheshwari, known as the 'Father of Indian Embryology', was a leading scientist in the field of embryology which is the study of plant reproductive organs. He developed the technique of *in-vitro* fertilisation in flowering plants by successfully fusing an egg and male gamete in a test tube to create new hybrid plants. He was also one of the first scientists to grow plant embryos on artificial nutrient media. His book, *An Introduction to the Embryology of Angiosperms* (1950), became a classic and is still widely used by scientists around the world.

Bridging Science and Society

Sexual reproduction in plants has an applied importance in plant breeding. There are several methods of plant breeding, such as selective breeding, artificial hybridisation, genetically engineered crops, and more. In selective breeding, farmers select plants of desirable characters for reproduction. Process of artificial hybridisation involves removal of the stamens from the flowers, covering it with a bagging to prevent self-pollination, and manual transfer of the pollens with desired characters. Genetic engineering is also applied by inserting the genetic material of desired characters into the DNA of the selected varieties. This leads to the development of new varieties, such as high yielding varieties, disease resistant varieties, and so on. This has revolutionised crop production in agriculture.

11.3 Sexual Reproduction in Animals

Reproduction in animals takes place through asexual and/or sexual method(s). We have studied different methods of asexual reproduction in different organisms, such as budding and spore formation, earlier in this chapter.

Grade 6 Curiosity Chapter 10

In many aquatic animals exhibiting sexual reproduction, such as frogs and most fish, fertilisation occurs outside the body. The female releases eggs into the water, and the male releases sperm over eggs for fertilisation to take place. This method of fertilisation is called **external fertilisation**. Although a large number of eggs are laid, many are destroyed by water currents or eaten by other animals. In reptiles, birds and mammals, fertilisation takes place inside the body of the female. This is called **internal fertilisation**. Here, the chances of survival of the young ones are generally higher because the fertilised egg or embryo is protected more in internal fertilisation (Table 11.4).

Pause and Ponder

4. Why do animals with external fertilisation generally produce more eggs than animals with internal fertilisation?
5. In animals, which fertilisation method the gametes are more protected?

11.4 Variations in Reproduction in Animals

Animals show a wide variety of methods of sexual reproduction. However, all animals face the basic challenge of ensuring that the male and the female gametes meet, and that the young ones survive long enough to grow and reproduce. Study the information given in Table 11.4 for four categories of animals.

Table 11.4: Variation in reproductive strategies among animals

Animal	Habitat	Mode of fertilisation	Number of eggs produced	Estimated survival of young ones
Fish	Water	External	100s – 1000s at a time	Low
Frog	Water/land	External	5,000 – 50,000 at a time	Low
Lizard	Land	Internal	2 – 20 at a time	Moderate
Bird	Water/land	Internal	1 – 15 at a time	Moderate to High

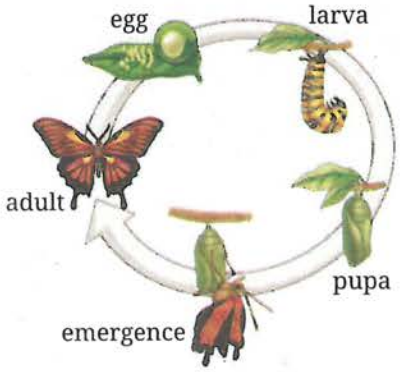


Fig. 11.17: Life cycle of a butterfly

Fish, amphibians, and insects produce several hundred to several thousand eggs at a time with yolk, which contains nutritive substances to nourish the developing embryos. The mother's body cannot provide such large quantities of yolk for so many eggs. The strategy these species adopt is that the yolk in the egg is just enough to produce a larva, which hatches from the egg. The larva, then gets nutrition by eating organic wastes like rotten food, manures and so on, and grows. This stage is an intermediate stage in its development, which is essentially a feeding stage. Once enough nutrition is accumulated, a transformation takes place and the adult body is formed — as seen in organisms, such as butterfly (Fig. 11.17) and frogs.

In contrast, reptiles and birds lay eggs, and each egg contains enough yolk to nourish the developing embryo until it hatches into a young one. In mammals, the zygote grows and develops inside the female body.

In some species, when the young ones are born, they are ready to find their own food, whereas in others an extended period of post-hatching or post-birth feeding and care is necessary. This broadly depends on how long the embryo develops inside an egg or inside the mother's body. Mammals typically feed their young ones via breast milk for some duration after birth.

11.5 Reproduction in Human Beings

11.5.1 Reproductive maturity

You have learnt about the physical and emotional changes that take place as a child grows into an adult, when reproductive organs mature and begin producing gametes (sperm in male and egg in female).

Grade 7 Curiosity Chapter 6

The human reproductive system consists of special organs (Fig. 11.18 and Fig. 11.19). When a sperm meets an egg inside the female body, they form a zygote that develops into an embryo and eventually into a foetus in the uterus. In this section, we will study how gametes form and meet, and how new life develops in human beings.

11.5.2 What are the parts of the male reproductive system?

The male reproductive system (Fig. 11.18) has organs that produce male germ cells called sperm and help them transfer to the female body. Sperm are produced in two oval-shaped organs called testes (testis singular), present in a pouch of skin called the scrotum. The scrotum keeps the testes slightly cooler than normal body temperature, which is necessary for sperm formation. The testes also produce a hormone (chemicals that regulate different functions), which controls sperm production and causes the physical changes seen in boys during puberty.

Grade 7 Curiosity Chapter 6

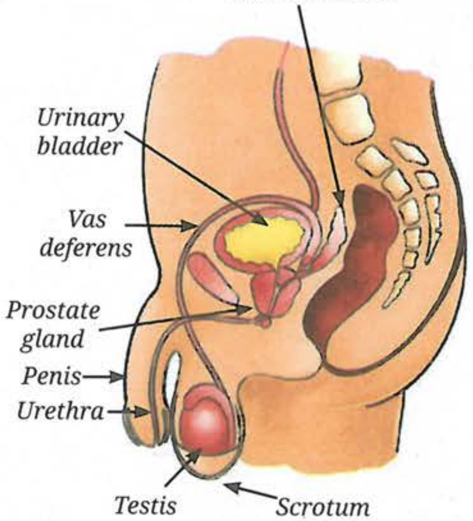


Fig. 11.18: Male reproductive system

From the testes, sperm travel through a long tube called the vas deferens, which ultimately opens into the urethra, a common passage for the urine and the sperm. Glands like the seminal vesicles and the prostate add fluids to nourish the sperm, and help them remain active and move. Each sperm has a head containing genetic material and a long tail that helps it swim towards the egg.

11.5.3 What are the parts of the female reproductive system?

Look at the Fig. 11.19 and identify various parts of the female reproductive system. The female reproductive system has a pair of ovaries, oviducts (fallopian tubes), a uterus, and a vagina. The ovaries produce the female germ cells (eggs) and also release hormones.

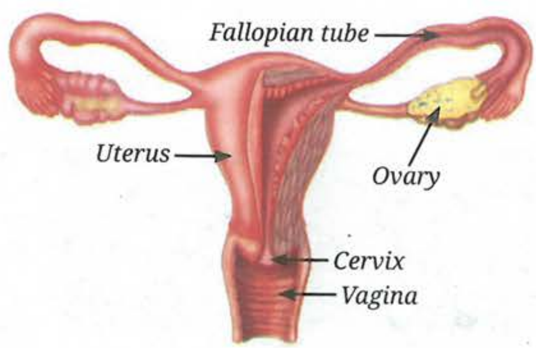


Fig. 11.19: Female reproductive system

Meet a Scientist

In-vitro Fertilisation (IVF) is a medical technique in which an egg and a sperm are combined outside the female body, usually in a laboratory dish. The resultant fertilised egg is then implanted in the uterus to begin a possible pregnancy. A baby born through this method is commonly known as a **test tube baby**, although the process actually occurs in a culture dish, not in a test tube. India holds a significant place in the history of IVF. In 1978, **Subhash Mukhopadhyay** of Kolkata pioneered India's first test tube baby, Kanupriya Agarwal (nicknamed Durga), through experimental IVF work.

The hormones bring about changes during puberty. The oviducts connect each ovary to the uterus. The uterus is a bag-like structure where a foetus develops. The uterus opens into the vagina through a narrow passage called the **cervix**.

11.5.4 How are reproductive cells made?

The process of the formation of gametes is called **gametogenesis**. It takes place in the testes and the ovaries. You have learnt in Activity 11.4 that gametes are formed by meiosis, in which the number of chromosomes is reduced to half. In humans, cells have 46 chromosomes, but sperm and eggs have only 23. This is important so that when they combine, the zygote has the same number of chromosomes as parents to form an individual. In males, gametogenesis results in the production of numerous tiny motile (moving), active sperm. In females, gametogenesis results in the formation of a single large egg. In sexual reproduction, male and female gametes differ greatly in size, number and structure (Table 11.5).

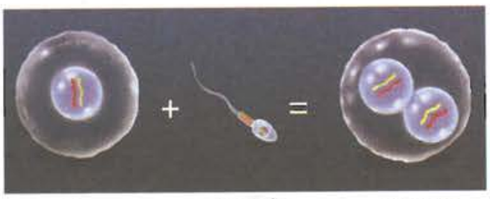
Table 11.5: Structure, size, and number of male and female gametes

Feature	Sperm	Egg
Size	Very small	Large
Number produced	Millions	Few
Stored nutrients	Absent	Present
Motility	Actively motile	Non-motile

This asymmetry between the male and female gametes is seen across most of the animals.

11.5.5 What happens when a sperm meets an egg?

At birth, a girl's ovaries already have millions of immature eggs. From puberty onwards, usually one mature egg is released every month from one of the ovaries. This is called **ovulation**. Before ovulation, the uterus starts to prepare itself; the inner lining becomes thick. As the ovulation happens, the egg travels from the ovary to the oviduct. During sexual intercourse, millions of sperm enter through the vagina. They swim through the reproductive tract and may reach the egg in the oviduct. If a sperm encounters an egg and succeeds in fusing with it, a zygote is formed (Fig. 11.20). The inner lining of the uterus becomes thicker and richer in blood vessels. The zygote undergoes a series of mitotic divisions while travelling to the uterus, and implants into the inner lining of the uterus to receive nourishment for development. This implantation marks the beginning of pregnancy.



Egg Sperm Zygote

Fig. 11.20: Process of fertilisation

11.5.6 What happens when an egg is not fertilised?

Grade 7 Curiosity Chapter 8

If an egg is not fertilised, it remains viable for about a day and then it degenerates. The inner lining of the uterus, which became thick and rich with blood vessels to receive and nourish the developing zygote, is no longer needed. So, the lining sheds. This lining, along with some blood, leaves the body through the vagina. This process is called **menstruation** or a period, and usually lasts 3 to 7 days. You have read about this process earlier. Now, you can connect it to the events of ovulation and fertilisation.

The cycle of ovulation, preparation of the uterus and menstruation repeats typically every 21 – 35 days (often around 28 days), and usually begins at puberty, between the ages of 10 – 14 in girls and continues till menopause i.e., around age 50 (Fig. 11.21).

Day 1 – 5:	Day 6 – 14:	Day 14:	Day 15 – 28:
Menstruation (Shedding of uterine lining)	**Uterine lining gradually rebuilds** (Egg starts maturing in ovary)	**Ovulation** (Ovary releases a mature egg)	**Uterine lining becomes thicker and rich with blood vessels** (If no fertilisation happens, it starts breaking down on approximately. 28th day and the cycle repeats)

Fig. 11.21: Key stages of the menstrual cycle across a typical 28-day period

Threads of Curiosity

What determines a baby's biological sex?

So far, you have learnt that every person has two sex chromosomes. Females have XX and males have XY chromosomes. The mother always contributes an X chromosome to a baby and the father contributes either an X (Female: XX) or a Y (Male: XY) chromosome. Now, from the above information, can you predict who determines the sex of a baby?

Bridging Science and Society

Hygiene practices to follow during menstruation (period):

- Use menstrual products, such as sanitary pads (preferably biodegradable ones), tampons, menstrual cups, etc.
- Wash regularly — clean your genital area with water. Avoid using soap, as this can disrupt the natural bacterial balance.
- Hand washing is the key — always wash your hands with soap and water, before and after changing your sanitary pad.
- Proper disposal of used products — wrap used pads in newspaper or the wrapper they came in before disposing them in a bin. Do not flush them down the toilet.
- Proper care for reusable products — if you use reusable pads, follow the manufacturer's instructions for cleaning. Ensure reusable pads are completely dry before their next use.
- Change menstrual products regularly — change pads in 4 – 6 hours, or more often if your flow is heavy.

Period is your pride

Menstruation is a sign of a healthy reproductive system, not something to be ashamed of. Using clean menstrual products, changing them as often as required, and disposing them responsibly helps in staying healthy and keeping your surroundings clean.

11.5.7 Pregnancy and childbirth

Pregnancy in humans lasts about nine months and is divided into three stages called **trimesters**. In the first trimester, the fertilised egg develops into an embryo during the first two months and major organs start forming during this time. From about the ninth week, the developing embryo is called a foetus, which continues to grow and develop. In the second trimester, the foetus grows bigger and stronger, and the mother can usually feel its movements. In the third trimester, the baby grows rapidly and gets ready for the life outside the womb (Figure 11.22). The uterus protects and nourishes the baby throughout this time. During childbirth, strong contractions of the muscles of the uterus help push the foetus out through the birth canal. In some cases, if a normal vaginal birth is not possible or safe for the mother or the foetus, doctors may use medical or surgical procedures to help deliver the baby safely.

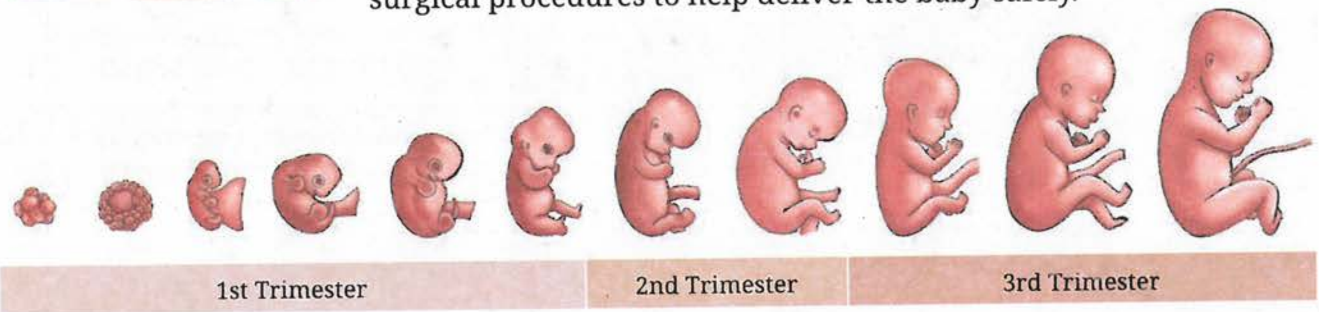


Fig. 11.22: Stages of pregnancy

After birth, a baby needs special care. Breastfeeding is essential because a mother's milk provides complete nutrition and protects the infant from many diseases. Newborns must be kept warm, vaccinated on time and handled gently. The mother's well-being is equally important. She requires nutritious food and adequate rest, and it is recommended for her to avoid harmful habits, such as smoking, consuming alcohol, or taking any medicines without medical advice. The health of the mother and the baby are closely connected, and require proper care and support.

Pause and Ponder

6. Ravi suddenly notices that he is growing taller rapidly, his shoulders are broadening, and his voice cracks. What stage of life is he entering?
7. Rina's period occurs every 28 days. Her last period was on the 5th of March. On which day is she most likely to get her next period?
8. A human zygote has just formed. How many chromosomes does it have?

11.5.8 Mother's health during pregnancy

A woman's health during pregnancy plays a vital role in the baby's growth and safety. She should eat a balanced diet rich in proteins, vitamins and minerals, attend regular medical check-ups, and follow her doctor's advice regarding light exercise and rest. Her emotional well-being is also important, and support from family members helps her remain healthy and stress-free.

Threads of Curiosity

Some mothers experience a form of anxiety and fatigue after the delivery of a baby. This is called post-partum depression, and it is a recognised condition that can be treated. Mothers should be encouraged to talk to a healthcare worker (such as a doctor, nurse, or ASHA worker) if they feel low or overwhelmed, so that they can get proper help and support.

Bridging Science and Society

More than 10 lakh Accredited Social Health Activist (ASHA) workers are health heroes across India. These community health workers are women trained to promote hygiene, immunisation, and family planning under the National Health Mission, especially in rural areas. They offer advice on maternal care, safe deliveries and contraceptive methods.

11.5.9 What does it mean to be sexually mature?

As we grow through adolescence, our bodies undergo many changes. A significant aspect of this growth is sexual maturation, meaning our bodies are becoming capable of reproduction. It is gradual and takes place alongside the overall body's growth but this does not mean we are fully ready for adult responsibilities. Sexual maturity (like the production of sperm in boys and menstrual cycles in girls) happens gradually, but emotional maturity takes longer. Being emotionally mature means handling feelings, communicating clearly and making thoughtful decisions.

11.5.10 How can unwanted pregnancies and infections be prevented?

During adolescence, the body becomes capable of reproduction but emotional and social maturity take longer to develop. Being ready for sexual activity is not only about physical changes but also about being able to make thoughtful and responsible decisions. Such responsible choices help prevent unplanned pregnancies, sexually transmitted infections and support healthy relationships.

Since sexual activity involves close physical contact, some infections can be transmitted from an infected person to an uninfected person. These are called **Sexually Transmitted Infections (STIs)** and include gonorrhoea, herpes, syphilis, genital warts, and HIV (which can eventually lead to AIDS). Some of these are not curable yet. Using condoms can prevent their transmission and also help prevent pregnancy.

To prevent unwanted pregnancy, different contraceptive (pregnancy-preventing) methods can be used. Some of them act as barriers, like condoms or vaginal covers, which stop sperm from reaching the egg. Some methods involve medicines (oral pills) that change the release of eggs by altering hormones, though these may have some side effects. Another method is the use of Intra-Uterine Devices (IUDs), such as copper-T that are placed in uterus to avoid pregnancy, though they may sometimes irritate the uterus (Fig. 11.23).

Grade 7 Curiosity Chapter 6

Pause and Ponder

9. What protective devices can be used during sexual activity to reduce the spread of STIs?
10. If a couple uses oral contraceptive pills but not condoms, which risks remain and why?

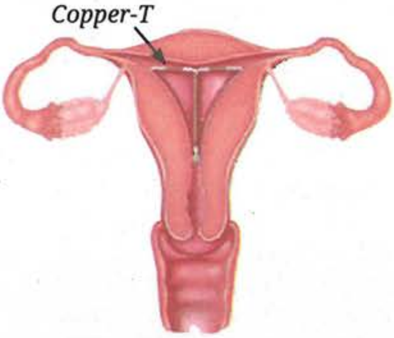


Fig. 11.23: Intra-Uterine Device

Surgical methods are also used to stop unwanted pregnancies. These include blocking the vas deferens in males or the fallopian tubes in females, so that the sperm and the egg cannot meet. In some cases, unwanted pregnancies can be removed by surgery, generally only within the first trimester of pregnancy, when the embryo is very small. This procedure is called **abortion**. The practice of self-selective abortion is a significant concern, often driven by a preference for a specific gender. This practice can lead to a marked imbalance in the societal sex-ratio. So, prenatal sex determination is strictly prohibited by law in India. This is important to maintain sex ratio for healthy forward-looking society.

Pause and Ponder

11. In many animals, the young ones can walk or find food soon after birth but human babies are completely dependent for a long time. What might be some advantages and disadvantages of this for humans as a species?

Bridging Science and Society

Indian scientists at the Central Drug Research Institute, Lucknow, developed the world's first non-steroidal and non-hormonal oral contraceptive pill. Taken once weekly, it avoids side effects like weight gain, nausea, or headaches. Safe, convenient, and effective, it is provided free through the National Family Planning Programme.

At a Glance

- Reproduction is the biological process by which living organisms produce new individuals of the same species. It ensures the continuity of life and the transfer of genetic information.
- There are two main types of reproduction: asexual and sexual.
- Asexual reproduction occurs in different ways, such as budding, spore formation and vegetative propagation in plants.
- A flower is the reproductive organ of a plant, with male stamen and female pistil.
- Pollination is the process of pollen transfer from anther to stigma, through self- or cross-pollination.
- During fertilisation, the pollen tube carries the sperm cells to the ovule, where it fuses to form a zygote. After fertilisation, the ovule becomes the seed and the ovary becomes the fruit.
- In humans, the testes produce sperm. Glands like testes, seminal vesicles and prostate produce male hormones.
- Ovaries produce eggs and female hormones. Ovulation takes place around the 14th day of the menstrual cycle.

- Birth control methods include condoms, pills, IUDs (Copper-T), etc.
- If fertilisation occurs, the zygote develops into an embryo and pregnancy begins. In human females, pregnancy usually lasts about nine months, during which the mother's body undergoes many changes to support the baby's growth.
- It is important for the mother to have proper nutrition, check-ups and rest, avoid harmful substances for the baby's healthy growth and support her own body during pregnancy.

Revise, Reflect, Refine

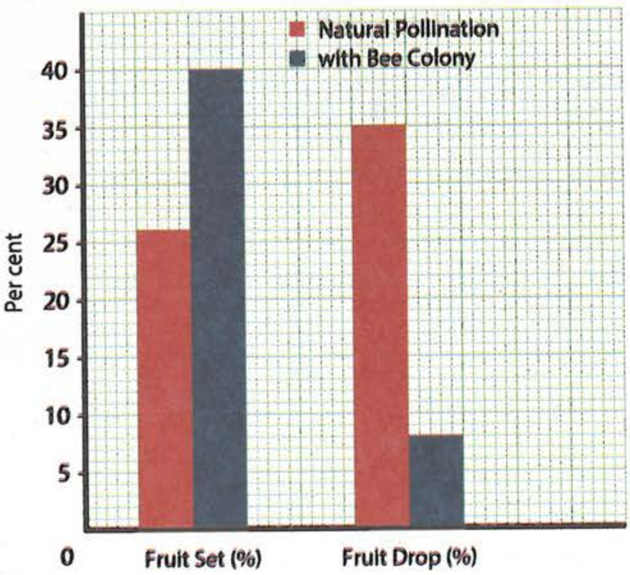
1. A flower's anthers are removed before it matures. Later, pollen from another plant of the same species is dusted onto its stigma and seeds are produced. Which process has been ensured here?
   (i) Self-pollination (ii) Cross-pollination
   (iii) Fertilisation (iv) Tissue culture
2. Arrange the following stages of sexual reproduction in plants in the correct order:
   (i) Pollen germination on stigma (ii) Fertilisation
   (iii) Pollination (iv) Formation of zygote
3. 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.
   (i) Both A and R are true, and R is the correct explanation of A.
   (ii) Both A and R are true, but R is not the correct explanation of A.
   (iii) A is true, but R is false.
   (iv) A is false, but R is true.
4. Why does asexual reproduction produce offsprings that are genetically identical to the parent?
5. Explain why the menstrual cycle stops during pregnancy.
6. Why are flowers that bloom at night white or light in colour as compared to flowers that bloom during the day?
7. Why do vegetatively propagated plants tend to be more vulnerable to diseases than sexually reproduced plants?
8. If all flowers in a type of plant were only capable of self-pollination, how would it affect the genetic diversity over several generations? Explain.
9. A farmer wants to produce a large number of genetically identical plants quickly. Suggest suitable reproduction methods and explain why they are effective.

10. Suresh prepares slides with pollen grains in different sugar concentrations (0%, 2.5%, 5%, 7.5%, 10%) to study the germination of pollen.
   (i) What are the different hypotheses which can be tested using this set-up?
   (ii) What parameters should be kept the same in this set-up?

11. Look at the picture given below and think in line with the given prompts and find out which type(s) of pollination might have been followed in these flowers —

Tomato	Wheat	Papaya
		
Stamens cover the stigma.	Flowers open after pollination.	Male and female flowers are often borne on different papaya trees.

12. In the lower Himalayan region of northern India, apples are an important cash crop that contribute significantly to farmer's livelihoods. The fruit yield in apple cultivation is declining continuously, associated with climate change and a significant decline in the population of natural pollinators. A researcher-farmer group set up two experimental apple orchards at two distinct locations: Places A and B. In apple orchards at Place A, they allowed natural pollinators to pollinate the flowers of the apple. In apple orchards at Place B, they applied mixed farming techniques of beekeeping. Along with honey, the farmer yielded apples. The yield of apples is depicted in Fig. 11.24, in terms of fruit setting (number of fruits/the total number of corresponding fruit-bearing branches) and fruit drop (premature falling of developing fruits) in the two types of experimental places of apple orchards.



   (i) What are the hypotheses the researcher-farmers group has thought of for this investigation?
   (ii) What are the different parameters in the experiment?
   (iii) Compare and analyse the data of two experimental orchards Places A and B, in terms of high yields of apple fruits.
   (iv) Based on your analysis, what do you infer from the data?

13. A student claims, "In humans, ovulation always happens on day 14 of the menstrual cycle". Critically examine this claim and state whether the claim is correct or not. Give at least two reasons for your answer.

The Journey Beyond

- Read about the 'Seed Village Programme' (Beej Gram Yojana) run by the Government of India. Why is it important to save indigenous seeds?
- Prepare a report on IVF, its uses and drawbacks. Discuss it with your class.
- Conduct a survey on crop fields. Interact with farmers on the crops grown on their farms and farm animals based on the following points —
  (i) Which crops do they grow through vegetative propagation?
  (ii) Which crops do they grow using seeds?
  (iii) Which seeds do they use — indigenous varieties or hybrid varieties? Why? How do they develop hybrid varieties in their fields?
  (iv) List the indigenous breeds and hybrid breeds of the farm animals they are using in their farming practices and how are they different from each other?
  (v) Discuss in class, and make a report on how asexual and sexual methods of reproduction are useful in agriculture.
- Explore the crop fields near your school and find out different pollination strategies adopted by different cereal and vegetable crop plants. Talk to farmers on the following points —
  (i) Pollinators of different crops
  (ii) Reason for the declining population of pollinators and their solutions

  Observe the pollinators visiting your school garden. Notice and record their activity. Let each student take pictures of at least five different types of pollinators and which plants they visit. Compile the data and showcase your work to discuss how pollination occurs in different plants.
- Assist your elders in cutting fruits in the kitchen. While cutting fruits like lady finger, tomato, brinjal, capsicum, papaya, orange, muskmelon and more, make your observations based on the following and draw diagrams —
  (i) When you cut a fruit longitudinally (Longitudinal Section: L.S.)
  (ii) When you cut a fruit transversely (Transverse Section: T.S.)
  (iii) Attachment of seeds

  Link your observations of the L.S. and T.S. of the fruit with the internal structure of the ovary of some species.

(a) L.S. of Tomato fruit

(b) T.S. of Tomato fruit

(c) L.S. of Tomato flower

The Quest Continues ...

Does a unicellular organism like amoeba or yeast ever 'grow old'? When it divides, it produces almost two identical copies. So, does aging happen at all?

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Chapter 12

Patterns in Life: Diversity and Classification

Think It Over

- What do you understand by biodiversity?
- How does the grouping of organisms help us understand diversity?
- On what basis, are plants and animals classified?
- How does classification help address problems in farming?

Have you ever wondered why some plants can survive long droughts while others cannot? Or, how certain insects protect crops while others damage them?

The Earth is home to an enormous variety of life forms. From microscopic organisms invisible to the naked eye to giant trees, from glowing jellyfish to soaring eagles, life exists in countless forms and habitats—from the snow-clad Himalayas to the coral reefs of the Andaman Sea. This immense variety of living organisms is known as **biodiversity**. Biodiversity is essential for life on the Earth. Every organism plays a role in keeping nature stable and functioning. Microscopic algae in the oceans release most of the oxygen we breathe. Fungi and bacteria decompose fallen leaves, and convert waste into manure, making the soil fertile. Birds, bees and bats pollinate flowers, while plants capture sunlight to prepare food that support nearly all life on the planet. These interconnections help sustain ecosystems and make the Earth suitable for living organisms.

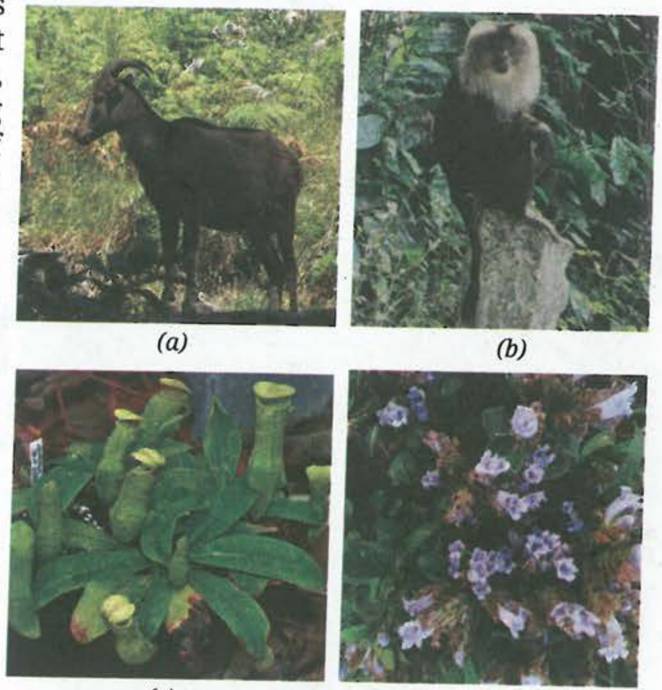
Humans, too, depend on biodiversity for food, shelter, medicines and livelihoods. For centuries, farmers relied on their practical knowledge to conserve diverse crop varieties with useful characteristics, such as drought tolerance, pest resistance and their ability to grow in nutrient poor soils. They realised that diversity reduces the risk of crop failure and strengthens food security.

In such a vast diversity, organisms share certain similarities while also showing many differences. To study diversity systematically, scientists group and classify organisms based on their shared characteristics and evolutionary relationships. Classification helps us understand how organisms are related, how they function and how we can use this knowledge in activities, such as ecosystem management, biodiversity conservation, sustainable farming, and so on.

12.1 India as a Biodiversity Hotspot

The natural landscape of our country is diverse—with mountains in the north, desert in the west, rainforests in the North East India, plateaus in the south, and long coastlines along the Arabian Sea and the Bay of Bengal. Each of these regions has distinct soil types and different climatic conditions like temperature and rainfall.

These diverse habitats together support a wide variety of species. Some of these species are restricted to particular regions of the world and are not found naturally anywhere else. Such species are called **endemic species**. For example, Nilgiri tahr (Fig. 12.1a), Lion-tailed macaque (Fig. 12.1b), Indian variety of the pitcher plant—*Nepenthes khasiana* (Fig. 12.1c) and *Neelakurinji* (Fig. 12.1d) are found only in India.



(a) (b) (c) (d)

Fig. 12.1: (a) Nilgiri tahr, (b) Lion-tailed macaque, (c) Nepenthes khasiana, and (d) Neelakurinji

Regions that support a large number of endemic species and have undergone significant habitat loss are known as biodiversity hotspots. These areas are particularly important for biodiversity conservation. Regions, such as the Western Ghats, Indo-Burma (including North East India), the Himalayas, Sundaland (including the Nicobar Islands), are some examples of global biodiversity hotspots. These areas are especially rich in number and in the diversity of organisms. Protecting these regions is equally important, as they support food webs and help ecosystems remain healthy.

12.2 How has the Biodiversity Evolved?

The biodiversity that we see today on the Earth was not always the same. Small differences among individuals affected their chances of survival and reproduction by helping them adapt to changed conditions. These differences accumulated over many generations and gave rise to new forms of life.

The diversity we see today is therefore, an outcome of continuous changes occurring over a vast span of time, shaped by interactions between organisms and their surroundings. The study of this biological diversity is possible through a systematic framework that is provided by classification.

India's Scientific Contributions

Some ancient Indian traditions, such as the *Sangam Tinai* classification of landscapes and the protection of sacred groves, demonstrate a sophisticated literary and cultural understanding of landscapes, and their biota. These customs effectively preserved locally diverse habitats, aligning with contemporary ecological principles, even if it is not articulated as a formal ecological theory.

12.3 How to Classify Organisms?

Activity 12.1: Let us compare and classify

Fig. 12.2 shows the diversity of animals in an ecosystem. **Observe** the image carefully. Can you guess how the organisms are grouped in the image?

Fig. 12.2: Day and night view of an ecosystem

1. Ponder on the questions given below:
   - Which animals can you identify in the given picture?
   - Where are they seen?
   - Which animals in the picture seem active:
     (i) during the day?
     (ii) during the night?
     (iii) both during the day and the night?
2. Record your observations in Table 12.1.

Table 12.1: Observation table for recording the data

Organism (draw or write name)	Where do you see it? (flying high in air/flying near the ground/tree/water/ forest floor)	When does it appear to be active? (day/night/ unsure)	Any visible feature(s)
Owl	Tree	Night	Feathers

3. Now, try grouping the same organisms in more than one way. Each time change the criterion you are using for grouping (Table 12.2).

Table 12.2: Grouping the organisms

The grouping criterion	Which organisms fit in this group?	What feature or pattern helped you decide?
Carnivore	Eagle, tiger, leopard	Eating habits

You may notice that the same organism can fit into different groups depending on the criterion you choose. This leads to an important question: how do scientists decide which features to use while grouping the living organisms? This question leads us to the idea of classification, a systematic way of organising the Earth's living diversity.

Pause and Ponder

1. If many organisms share common features, could they also share a common ancestry?

12.3.1 Some criteria to classify living organisms

Scientists often look at broad and easily visible features, and then look at more detailed features. They use a number of characteristics to group living organisms, some of which are given below:

1. External features — visible characteristics, such as shape, size and body organisation.
2. Mode of nutrition — autotrophic or heterotrophic.
3. Internal structures — skeletal patterns, presence or absence of organs and different types of tissues.
4. Cell structure — whether the organism is unicellular or multicellular, the cell is eukaryote or prokaryote, presence or absence of cell wall.
5. Ecological role — producer, consumer, or decomposer.
6. Reproduction — asexual and/or sexual methods.
7. Genetic similarity — similarities in inherited features, which scientists study in detail using DNA.

These features help in understanding the similarities and differences among organisms. Similar features in organisms suggest that they have evolved from common ancestors.

(a) Rufous-necked hornbill

(b) Oriental Pied hornbill

(c) Great hornbill

(d) Wreathed hornbill

Fig. 12.3: Four different species of hornbill found in the Pakke Tiger Reserve

12.4 The Need for Classification

Imagine walking into a huge library where thousands of books are scattered all over the floor. You want to read the book, *On the Origin of Species* by Charles Darwin. Where would you begin? Without arranging books into subjects, authors, or sections, finding any book would be difficult. In the same way, the Earth is home to millions of organisms. Therefore, classifying these organisms systematically helps us in understanding them better.

Activity 12.2: Let us read a case study

Carefully read the given case study of Pakke Tiger Reserve.

The Pakke Tiger Reserve in Arunachal Pradesh is a forest where scientists have recorded nearly 300 bird species, which is striking given that India as a whole has about 1,300 bird species. Pakke is also known for supporting four species of hornbills — the Rufous-necked Hornbill, the Oriental Pied Hornbill, the Great Hornbill, and the Wreathed Hornbill (Fig. 12.3). These large birds nest only in large, old trees with suitable cavities and feed on specific fruits. As a result, different hornbill species are found in different parts of the forest depending on tree size and fruit availability. Studying such patterns allows scientists to ask precise questions about biodiversity, such as —

- How are species distributed within a forest? Which plants and animals are closely linked?
- How does classifying the four hornbill species help us understand biodiversity?

Think and discuss the case based on the following questions —

(i) How can scientists keep track of so many species?

(ii) The four hornbills look similar in some ways. What features can help scientists distinguish them from one another?

(iii) What would happen if the large, old trees disappeared from the forest?

Many organisms show similarities in their external features, internal structure (such as tissues and organs) and cellular organisation. To make the study of such vast diversity easier, scientists group organisms based on their similarities and/or differences. This grouping helps to organise information, understand relationships among organisms and study life in a systematic manner. This scientific system of grouping living organisms is known as **biological classification**.

Biological classification helps us in various ways, such as —

1. It makes the study of living organisms more organised and systematic.
2. It helps us understand the similarities and differences among living beings.
3. It helps us understand how different organisms are related to one another and how they interact.
4. It helps us in identifying and naming the newly discovered organisms.
5. It supports biodiversity conservation by identifying the organisms that are under the threat of extinction.

6. It allows scientists all over the world to discuss about organisms using a common system.

12.5 Biological Classification Systems Over Time

In the previous section, you have learnt to identify various criteria for classifying the huge biodiversity in the world. Scientists have developed different classification systems over time, based on the knowledge available.

Aristotle, around the 4th century BCE, grouped animals based on their habitat—land, water and air. He also grouped them based on their external appearances. However, this system had limitations because it relied mainly on easily observable external characteristics. In the 18th century, scientists introduced the two kingdom system. All living organisms were divided into Plantae and Animalia.

India's Scientific Contributions

The *Rigveda* and the *Brihat Samhita* classify animals on the basis of their habitat (terrestrial, aquatic and aerial), behaviour patterns and ecological roles.

Plantae—organisms that do not move from one place to another and synthesise their own food.

Animalia—organisms that move from one place to another and depends on other organisms for food.

But this system created confusion. Where should organisms like *Amoeba, Paramecium* and bacteria be placed? *Amoeba* and *Paramecium* move like animals but are unicellular and heterotrophic. However, plants and animals are multicellular organisms. To address this, scientists added a third kingdom, Protista, to include unicellular microscopic organisms.

As microscopes improved, scientists noticed an important difference. An *amoeba* has a true nucleus (membrane-bound) but bacteria do not. Since both are unicellular but very different, bacteria were placed in a separate kingdom called the Monera. This led to a four kingdom classification system—Plantae, Animalia, Protista and Monera. The kingdom Protista includes mostly unicellular organisms with a true nucleus. Later, scientists noticed that fungi like mushrooms, do not move like plants but have a heterotrophic mode of nutrition. They obtain nutrients by absorption, many absorb nutrients from dead and decaying matter (though some are symbiotic and some are parasitic). Therefore, fungi were placed in a separate kingdom. This resulted in the five kingdom classification, which includes Monera, Protista, Fungi, Plantae and Animalia (Fig. 12.4).

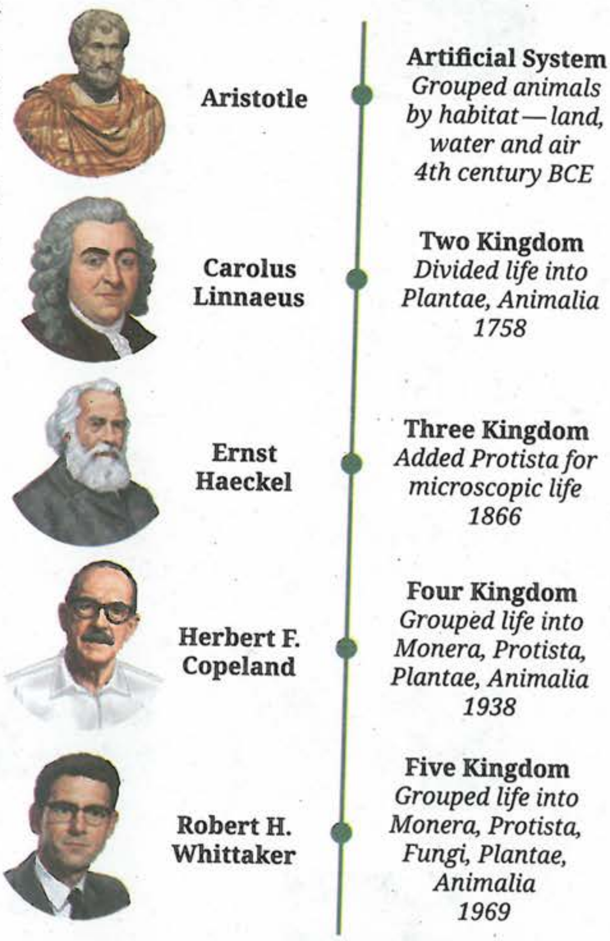


Fig. 12.4: Timeline of the classification systems

12.6 Five Kingdom Classification

In the five kingdom classification, all life forms are grouped based on certain common features.

Activity 12.3: Let us study

1. Study the concept map (Fig. 12.5).
2. List the criteria which form the basis of five kingdom classification.

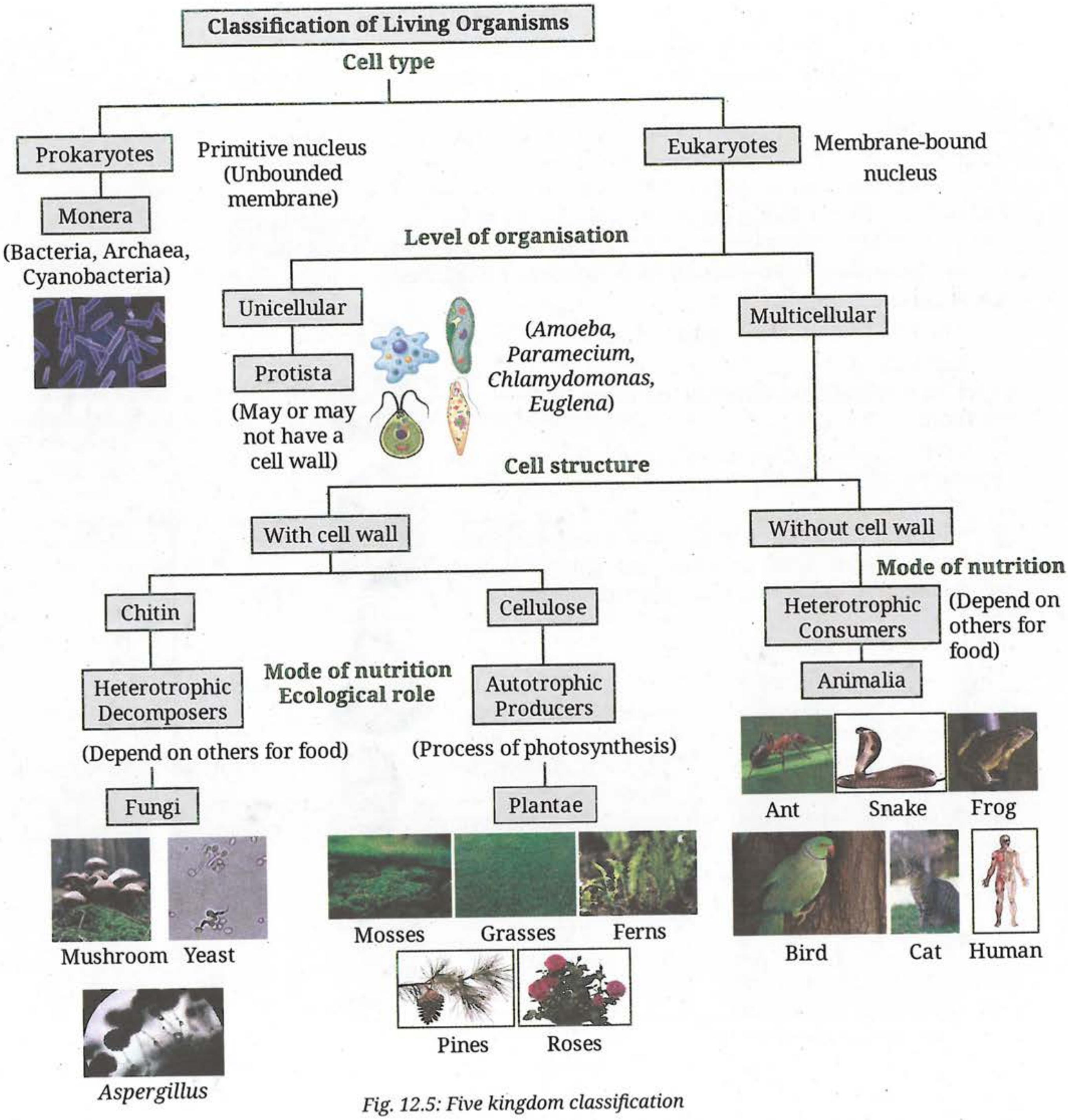


Fig. 12.5: Five kingdom classification

3. **Compare** the criteria you have listed after studying the concept map and the criteria given below:
   - Cell type — prokaryote or eukaryote
   - Cell structure — presence or absence of a cell wall

- Level of organisation — unicellular or multicellular
- Mode of nutrition — autotrophic or heterotrophic

12.6.1. Kingdom Monera — Unicellular prokaryotes

Activity 12.4: Let us explore

1. In the school laboratory, observe the available permanent slides of bacteria and cyanobacteria under the microscope.
2. Compare them with Fig. 12.6.

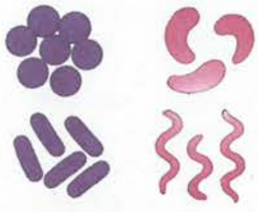


Fig. 12.6 Members of the Kingdom Monera

What do you observe? Bacteria and cyanobacteria are single-celled prokaryotes that are grouped under Monera (Fig. 12.6). Bacteria are found everywhere, including soil, water, air, hot springs and other extreme environments where most organisms cannot survive and even inside the human bodies. They are also found in the gut of ruminants and are responsible for the production of biogas from the dung of these animals. Some bacteria are harmful (pathogens) and cause diseases but many are useful like *Lactobacillus* and *Rhizobium*. Cyanobacteria are autotrophs and decomposers. In addition to nutrient cycling, some bacteria also break down pollutants like oil, pesticides, sewage, and so on.

Threads of Curiosity

Cyanobacteria (blue-green algae) were among the first organisms to produce oxygen through photosynthesis. About 2.5 billion years ago, oxygen accumulated in the atmosphere, made the Earth suitable for other forms of life. Fossils of ancient cyanobacteria are found in structures called **stromatolites**. They were found in Rajasthan and Madhya Pradesh. They provide some of the earliest evidence of life on the Earth.

Bridging Science and Society

Ram Bux Singh is popularly known as the 'Father of Modern Biogas'. He was a pioneering Indian scientist who contributed to the development of biogas technology. In 1957, he established India's first scientifically designed biogas plant at Ramnagar, Sitapur, Uttar Pradesh, which marked the beginning of systematic modern biogas research in the country. He later worked extensively on developing low-cost, efficient biogas plants for rural areas. He also served as an international consultant and helped set up biogas plants in several countries. His lifelong efforts played a crucial role in promoting renewable energy, waste management and sustainable development through technology.

12.6.2 Kingdom Protista — Unicellular eukaryotes

All single-celled eukaryotes without cell wall or with cell wall made up of cellulose are grouped under the kingdom protista. They are microscopic and highly diverse organisms. You can study some of these protists (Fig. 12.7) by making a slide from hay infusion as explained below.

Activity 12.5: Let us make

To make a hay infusion, follow the steps given below —

1. Collect a small sample of grass after the lawn has been mowed, or collect straw or fodder.
2. Take a small glass bottle and fill one fourth of it with the grass, straw or fodder.
3. Fill the bottle with stagnant water or pond water and mix it with the collected plant material.
4. Cover the bottle with a muslin cloth and tie it using a thread.
5. Keep the bottle aside undisturbed for a week.

Amoeba *Paramecium* *Euglena*

Fig. 12.7: Microscopic illustration of common protists

Pause and Ponder

2. How can a single-celled organism carry out all its life processes when billions of cells are required to perform similar functions in multicellular organisms like us?

(a) Yeast

Aspergillus

(c) Mushrooms

Fig. 12.8: Common fungi

6. Slightly open the mouth of the bottle by removing the muslin cloth, just enough to insert a dropper inside it and carefully take a drop of water.
7. Put the drop of water on a clean slide and observe it under a microscope.

Caution: The hay infusion may smell bad. Therefore, take precaution during lab exercises.

- Wear a lab coat, mask and hand gloves.
- Discard the hay infusion after autoclaving.

Do you notice moving organisms in the drop of water under the microscope? Can you **identify** them by comparing them with Fig. 12.7?

Protista includes single-celled eukaryotic organisms that live in water or moist places (Fig. 12.7). Some are autotrophic and others are heterotrophic. Protists are an important link in aquatic food chains, some produce oxygen while others serve as food for small animals. Some protists function as decomposers and help in nutrient cycling.

12.6.3 Kingdom Fungi — Multicellular, heterotrophic eukaryotes with a cell wall

Fungi are mostly multicellular eukaryotes with cell walls made of chitin. They do not make their own food. They either absorb nutrients from dead or decaying matter through fine filaments (which together form a network known as mycelium). Most of the fungi are saprophytes and therefore, they play a very important ecological role as decomposers, that means, they feed on dead organic matter, such as fallen leaves, twigs or dead organisms. They break down the complex organic matter into simpler substances and make them readily available in soil as minerals. Some of the fungi establish a mutualistic (symbiotic) relationship with other organisms while others live as parasites, and cause diseases in plants and animals. They reproduce both sexually and asexually, often by forming spores, and grow best in warm and moist conditions.

Yeast (Fig. 12.8a) and bread mould are common fungi. However, yeast is a unicellular organism, since its cell wall is made up of chitin, it has been put under fungi. Mushrooms (Fig. 12.8c) are macroscopic fungi that reproduce by spores. Some fungi like *Aspergillus* (Fig. 12.8b) and *Penicillium* are used to make enzymes and antibiotics. Fungi are important decomposers and help recycle nutrients. Without them, the decay of dead plants and animals would be greatly reduced, adversely affecting the soil fertility and ecological balance.

Bridging Science and Society

Wild edible mushrooms are a valuable dietary food with high nutritional and medicinal values. They are important forest resources used and conserved by many communities, including tribal communities in India. These communities possess traditional knowledge about the edible and poisonous mushrooms based on folk taxonomy. Some wild mushrooms are used as sources of food and some as medicine for treating various ailments. Nowadays, mushroom cultivation is becoming a promising vocation for livelihood. Mushroom farming is easy and accessible due to its minimal space requirement, low investment and fast cycle (30 – 45 days).

12.6.4 Kingdom Plantae — Multicellular, autotrophic eukaryotes with a cell wall

Plants are multicellular, autotrophic organisms that perform photosynthesis. Their cells have a rigid cell wall primarily made up of cellulose, which provides support and protection. All plants belong to the kingdom Plantae. Plants form the base of most of the food chains and release oxygen which is essential for life on the Earth. Kingdom Plantae is further divided into five classes.

Grade 7 Curiosity Chapter 10

Plantae

Class

- Thallophyta
- Bryophyta
- Pteridophyta
- Gymnosperm
- Angiosperm

Thallophyta (algae) — Primitive plants

Thallophytes (*thallos* means undifferentiated body and *phyton* means plant) are among the simplest plant forms and are mostly found in water or moist environments. They form a thallus, a simple body that allows direct exchange of gases, nutrients and water with the surroundings. They are well-adapted to aquatic habitats. An example of Thallophyta is *Spirogyra* (Fig. 12.9).

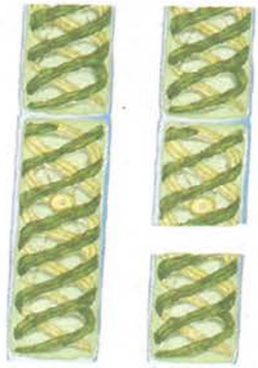


Fig. 12.9: Spirogyra

Bridging Science and Society

Have you ever seen white-green patches on the tree trunk, damp walls or stones? What do you think about these patches? Visit a village and talk to an elderly person about these patches. They recognise these patches as an indicator of a pollution-free environment. In fact, the lichens change their colour with air pollutants. Based on their colour, researchers can find out the concentration of pollutants in the air. Therefore, they are natural bioindicators for the measurement of air quality. Villagers also collect these as forest produce for utilisation in their daily life. Some types of lichen, commonly called *patthar ke phool* are used as a spice, while some are used as medicines, and also for making dyes since ancient times to give maroon, violet, or burgundy colour to woollen and silk fabrics. Biologically, these are symbiotic (mutual associations of two organisms) — one partner is an autotrophic alga and the other one is a heterotrophic fungus. Fungal partners provide protection, and algal partners photosynthesise and provide food. Some lichens are poisonous, so it is important to classify and identify them properly for safe and proper utilisation.

Bryophyta — First steps on land, still need water

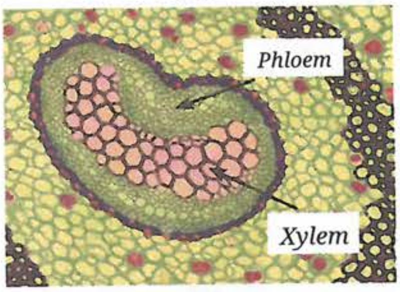
Bryophytes (*bryon* means moss and *phyton* means plant), such as mosses and liverworts (Fig. 12.10), which represents an important shift from water to land. You might have seen them as large green mats on damp rocks or even on the walls of some old buildings, or even on soil surfaces as green mats. Bryophytes have a more differentiated body as compared to thallophytes. They have root-like structures called **rhizoids,** and may possess stem-like and leaf-like simple structures. Bryophytes survive in moist and shady places, growing as green mats on the soil, especially during the monsoons. Examples of Bryophytes include *Marchantia* and moss (Fig. 12.10).

(a) Marchantia

(b) Moss

Fig. 12.10: Members of class Bryophyta

(a)



(b)

Fig. 12.11: (a) Fern, and (b) cross section of a fern stem

Pause and Ponder

3. Which plant features reduce their dependence on water but still require moist conditions?
4. Why do taller plants need specialised transport tissues?
5. How do seeds and fruits affect, where and how plants can survive?

Fig. 12.12: Cone of pine

Activity 12.6: Let us explore

1. Observe some bryophytes with the help of a hand lens. Collect them in a watch glass.
2. Put a drop of water on it and observe it under a dissecting microscope. A dissecting microscope enables us to view magnified images of live specimens.

How do they **differ** from the leaves that you usually observe in your surroundings?

Bryophytes require water for reproduction. Therefore, they are called the 'amphibians' of the plant kingdom. They show how plants began to colonise land, while remaining dependent on moisture.

Pteridophyta — Adaptation to land and having structural transport system

Look at Fig. 12.11a. What changes do you observe in the plant structure as compared to thallophytes and bryophytes? Pteridophytes (pteris derived from *pteron* means feather and *phyton* means plant), such as ferns, possess true roots, stems and leaves. How do you think that the transport of water and food takes place in all parts of these plants? One possible explanation is that ferns have specialised transport tissue. How can you test this explanation? A cross section of the stem of a fern can be cut and seen under a microscope. You may also observe a permanent slide of a cross section of a fern stem available in your school laboratory. The cross section shows vascular tissues, xylem and phloem, which transport water and food, respectively, throughout the plant (Fig. 12.11b). Pteridophytes require aquatic conditions for reproduction and do not produce seeds.

Activity 12.7: Let us compare

1. Recall the cross section of the sunflower stem you have studied in Chapter 3 (Fig. 3.7).
2. Compare the cross section of the stem of a fern, a pteridophytic plant (Fig. 12.11) with a cross section of sunflower stem you studied in Chapter 3 (Fig. 3.7).
3. What difference do you observe in the vascular tissue of the fern stem and of the stem of higher plants? Write your observations. Share and discuss them in class.

Gymnosperms — Reproduction without water

Gymnosperms (*gymnos* means naked and *spermos* means seed), such as pines (Fig. 12.12) and cycads are well-adapted to cold and dry regions. Their needle-like or scale-like leaves reduce water loss and withstand harsh conditions. They produce seeds, which protect the developing embryo and contain stored food. Gymnosperms do not require aquatic conditions for fertilisation. Their seeds are not enclosed in fruits and are often exposed on cones.

Angiosperms — Efficient reproduction and seed dispersal

Angiosperms (*angeion* means vessel and *spermos* means seeds) or flowering plants, represent plants with the most complex body organisation.

Grade 6 Curiosity Chapter 2

They produce flowers and fruits (Fig. 12.13). Flowers attract pollinators, increasing the efficiency of reproduction, while fruits help spread seeds to new locations. These features allow angiosperms to occupy a wide range of environments. Therefore, they are the most diverse plant group on the Earth.

Fig. 12.13: An angiosperm tree (Gulmohar)

Activity 12.8: Let us discuss

Collect different leaves from your surroundings, and observe their shape and venation. Group them as monocots or dicots. **Discuss** how their structures help them adapt in different conditions to survive.

Bridging Science and Society

One of the earliest scientific books on Indian plants, *Hortus Malabaricus*, was compiled in the 17th century by Hendrik van Rheede with the help of Itty Achudan (an Indian Herbalist, Botanist and Physician) and other local experts. It describes hundreds of plant species and their medicinal uses, showing how traditional knowledge and science can work together.

Different plant groups present different ways of solving problems, each with advantages and challenges or exceptions for survival.

Activity 12.9: Let us study

1. Carefully study the salient features of each plant group.
2. **Analyse** the salient features, and write the advantages for survival of the group and the exceptions or challenges faced in the given columns.

Table 12.3: Classes of Kingdom Plantae with their advantages and challenges

Plant groups and salient features	Advantages of the group for survival	Exceptions/ Challenges
Thallopyta • Their body is like a thallus which facilitates easy absorption of water and nutrients, and exchange of gases from the surroundings.	• Simple plant body facilitates survival and its dispersal in water.	• They cannot live on land. ________ ________
Bryophyta • Unlike algae, this group of plants began to colonise land but with strong dependence on moisture. • Plant body shows slight differentiation in body parts but not in root, stem, or leaves. • They lack vascular tissues for transporting water and food. • They require water for reproduction, as male reproductive cells must swim to reach female cells.	• They are plant amphibians. • Their body is adapted to live on moist land. ________ ________	• They always need moisture. ________ ________
Pteridophyta • Pteridophytes possess true roots, stems and leaves. • They have vascular tissues (xylem and phloem) that transport water and food throughout the plant. • They still depend on water for reproduction. • They do not produce seeds.	• They live on land. • They transport food and water to all parts of the plant. ________ ________	• Reproduction does not take place without water. ________ ________

Gymnosperm • They live on land. • They have needle-like leaves which reduce water loss. • Water is not essential for fertilisation. • Their seeds are not enclosed in fruits and are exposed on cones.	• Leaves are adapted for dry conditions. • They do not require water for reproduction. • They form seeds for continuity of life. ________________ ________________	• Seeds are not covered in the form of fruits. ________________ ________________
Angiosperm • They possess well-developed roots, stems and leaves. • They undergo sexual reproduction through flowers. • Their seeds are enclosed within fruits. • Their seeds disperse through insects or birds, animals, wind, or water.	• They produce flowers, fruits and seeds. • They have a well-developed system for reproduction. • They produce seeds for continuity of life. • Their seeds are covered. ________________ ________________	• Reproduction is dependent on pollination by different agents. • They have complex processes through a well-developed tissue system. ________________ ________________

From algae to angiosperms, plant groups show a sequence of structural changes that help plants meet the challenges of life on land. Early plants relied on water for support and reproduction. Gradually, plant groups evolved transport tissues, seeds and flowers.

Overall, the diversity of plant forms reflects multiple ways of balancing growth, transport, reproduction and survival in different environments.

12.6.5 Kingdom Animalia — Multicellular, heterotrophic eukaryotes

Animals are multicellular and heterotrophic organisms. They depend on other organisms for their food. Most animals exhibit the characteristics of locomotion, rapid response to stimuli and coordinated behaviour. These abilities allow animals to actively search for food, avoid predators and interact dynamically with their surroundings.

One of the major criteria for classifying animals is the presence or absence of a notochord, which is a flexible rod-shaped structure. Based on the absence or presence of the notochord, animals are classified into two groups — non-chordata (invertebrata) and chordata. In some chordates, notochord acts as a precursor for the development of the vertebral column. The chordata is further classified as protochordata and vertebrata.

Invertebrates — Animals without a notochord

Invertebrates lack a notochord, yet they show a wide range of body organisation, from a simple structure to complex organ systems. Studying invertebrates allows us to trace how the animal body gradually changed over time, leading to advancement in traits like movement, diverse feeding habits, and enhanced control and coordination, while also introducing exceptions and new challenges.

Porifera (pore-bearers) — Multicellularity without tissues

Sponges (Fig. 12.16a) represent one of the simplest animal body plans. They are multicellular but lack organisation of tissues and organs. Numerous pores in their body allow water to continuously flow through it, bringing food particles and oxygen directly to individual cells, carrying the waste away. Sponges remain fixed in one place and are found in aquatic environments. Do you think they would be able to survive on land? Why or why not?

Threads of Curiosity

Research studies show that one kilogram of sponge can filter up to 24,000 litres of sea water per day.

Cnidaria — True tissues and active feeding

Cnidarians, such as *Hydra* (Fig. 12.14), jellyfish (Fig. 12.16b) and corals show a major change in body organisation. Tissue-level organisation is present in them which allows specialised cells to perform specific functions, such as tentacles, which are used for capturing prey. Unlike poriferans, cnidarians can catch their prey using tentacles instead of depending on water currents to bring food particles inside through pores. However, cnidarians possess a single opening that functions for both food intake and waste removal. Can you hypothesise what limitations this body structure might have?

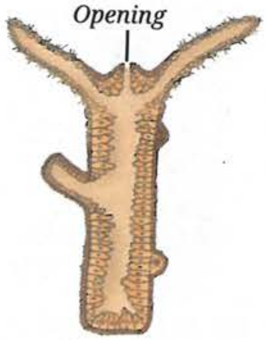


Fig. 12.14: Longitudinal section of hydra showing tissue level organisation

Platyhelminthes (flatworms) — Bilateral symmetry and directional movement

Flatworms show organisational advancement through bilateral symmetry (organism's body can be divided into two halves along one plane), in which the body has distinct head-tail and front-back regions. This body organisation allows better coordination of movement and this is the beginning of directional activity. Their flattened bodies permit efficient diffusion of gases without specialised respiratory organs but there is still a single opening for food intake and waste elimination.

Many flatworms have adopted a parasitic lifestyle. Hooks and suckers are present in the parasitic forms which helps them to attach firmly to the host tissues for obtaining nutrients (Fig. 12.16c).

Bridging Science and Society

Some infectious diseases are caused by parasitic worms. They enter our bodies through contaminated water and food. They live inside our body, especially in the alimentary canal (the digestive system). These worms take nutrients from our body and live like parasites (the organism that lives in or on another organism is called the host). For this reason, it is suggested to wash your hands properly, maintain personal hygiene and good sanitary habits, consume properly cooked food and boiled or filtered drinking water.

Nematoda (roundworms) — Efficient body design with two openings

Roundworms have elongated, cylindrical bodies (Fig. 12.16d). This body structure allows their efficient movement through soil, water, or host tissues. This body form increases the range of environment in which roundworms can survive, despite relatively simple internal organisation. The body has two openings (mouth and anus). The organ system level of body organisation is distinct in male and female worms.

Annelida (segmented worms) — segmentation and body cavities

Annelids, such as earthworms (Fig. 12.16e), represent a notable development in body organisation. Their bodies are cylindrical and are divided into segments. What advantages segmentation might offer to an organism? Observing how an earthworm moves may help you form a hypothesis. They possess organ system level of organisation. Presence of muscles help them in locomotion, and nerve cord helps in control and coordination.

Segmentation allows greater flexibility and more precise control of movements. A body cavity is also present in them as shown in Fig. 12.15.

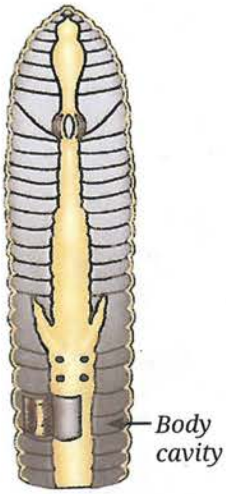


Fig. 12.15: Internal structure of an earthworm: Organ formation and body cavity

Arthropoda — Jointed appendages and an external skeleton

Arthropods (*arthro* means limbs and *poda* means appendages) includes insects, crabs (Fig. 12.16f) and spiders. They have segmented bodies with different segments specialised for different functions. A defining structural feature of arthropods is the development of a hard external skeleton (rigid external covering). What advantages can the outer covering provide?

This outer covering provides protection, reduces water loss and supports powerful muscles, allowing arthropods to survive in dry and exposed environments.

Pause and Ponder

6. An earthworm (annelida) and a beetle (arthropoda), both have segmented bodies but the beetle has a hard external skeleton. How does the beetle's external skeleton help it survive?

Image	 (a)	 (b)	 (c)	 (d)
	Porifera	Cnidaria	Platyhelminthes	Nematoda
Habitat	Water (Marine)	Water (Fresh and marine)	Water/inside host	Soil/water/inside host
Level of organisation	Cellular	Tissue	Organ	Organ system (digestive system)
Skeleton	X	X	X	X

Fig. 12.16: The animal kingdom

Mollusca — Organ system level organisation with soft bodies

Molluscs, such as snails (12.16g), squids and octopuses show organ system level organisation with soft bodies. In many molluscs, the development of a shell provides protection to these soft bodies. Their body is segmented with a distinct head, a muscular foot and a hump.

This group shows how a basic body plan can be modified in different directions depending on environmental demands.

Echinodermata — Internal support without a notochord

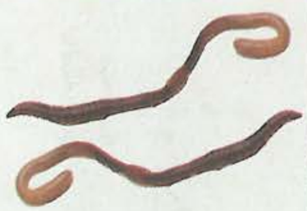
Echinoderms (*echinos* means spiny and *derma* means skin), such as starfish (Fig 12.16h) and sea urchins possess a hard internal skeleton made of calcium carbonate. Although they lack a notochord, this internal skeleton provides them protection and controlled movement. Their body organisation is quite like that of more complex animals, showing a gradual shift towards internal skeletal support.

Looking across invertebrates

From sponges to echinoderms, animal body structure shows a pattern of increasing complexity in body organisation. New structural features improve feeding, movement and protection but often introduce new challenges. These help explain survival in diverse environments.

Protochordates — The appearance of the notochord

Protochordates (like *Amphioxus*) possess a notochord at least once during their life. This structure provides internal support without restricting movement and represents a crucial change in body organisation. Protochordates are a primitive type of chordates which help us understand how animals with a notochord may have arisen from simpler forms.

 (e)	 (f)	 (g)	 (h)
Annelida	Arthropoda	Mollusca	Echinodermata
Moist soil/water	Land/water	Water/moist land	Marine water
Organ system	Organ system	Organ system	Organ system
X	Exoskeleton	Exoskeleton	Endoskeleton

Vertebrates — Animals with a backbone

Vertebrates possess a vertebral column (backbone), an internal skeletal structure that supports the body and protects vital organs, such as the brain and the spinal cord. This internal framework allows a larger body size, efficient movement and the development of complex organ systems. Vertebrates show advanced sensory abilities and coordinated behaviour.

Vertebrates are classified into five groups, namely fish, amphibians, reptiles, birds and mammals based on the broad patterns of their habitat use, body covering and reproduction.

Bridging Science and Society

How do forests with rich and highly diverse flora and fauna work as a barrier and reduce the impact of disasters?

Forests with rich biodiversity play a vital role to create physical, biological and chemical barriers to protect against challenges. Some of the examples are as follows:

- Large diversity of trees in mangrove forests helped during the super cyclone that hit Orissa in 1999. Villages with more mangroves experienced less destruction.
- Rich biodiversity generally correlates with lower tick-borne disease risk. In the Western Ghats of India, where forest diversity acts as a biological barrier against Monkey Fever (Kyasanur Forest Disease, KFD), as many animals are the hosts where the virus cannot replicate inside their bodies.
- Diverse microorganisms in forest soils and plant roots absorb, transform, or break down pollutants. This improves water quality and protects ecosystems. Mangrove soils trap sediments and heavy metals, preventing pollution from spreading into oceans and rivers.

12.7 Adaptations as Outcomes of Structural Change

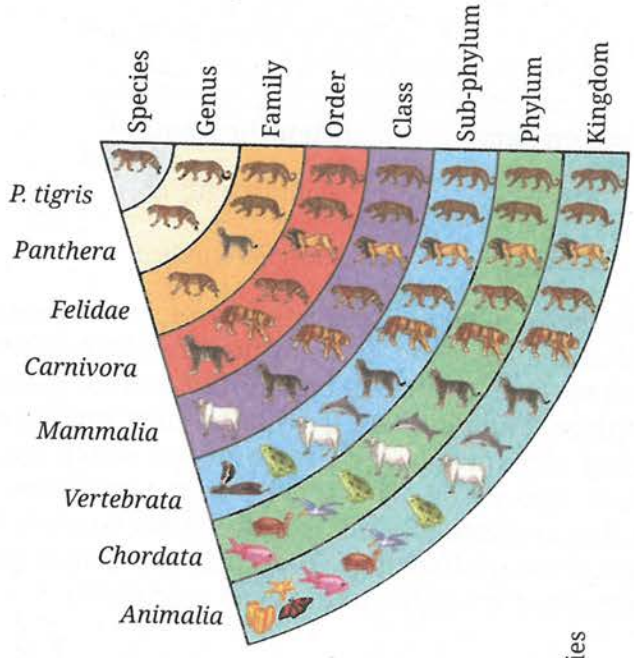
The diversity seen in animals today are outcomes of changes in the body structure over long periods of time. Fins and gills allow fish to move and breathe in water. Feathers and hollow bones make flight possible in birds. Fat storage in camels and thick fur in polar bears illustrate how structural features support survival under extreme conditions. In mammals, mammary glands represent an additional structural and functional change that improves the survival of young ones. These features are interconnected and reflect how different vertebrates tackle the challenges of survival in different environments. All these characteristics show that animal diversity reflects a wide range of body forms found in organisms living under different environmental conditions.

12.7.1 The hierarchical nature of classification

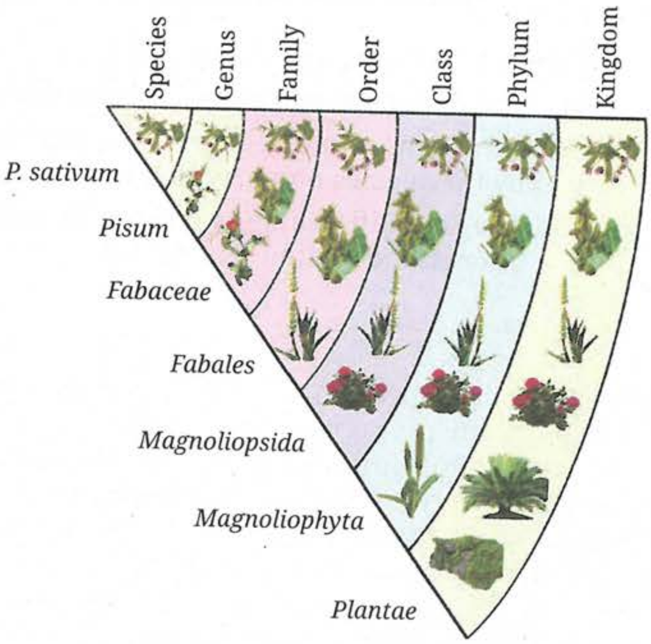
Observe and analyse Fig. 12.17. What do you infer? Classification follows a step-by-step order, starting from very broad groups, and moving towards smaller and more specific ones. At each lower level, organisms share more common features. Every lower group is a part of the group above it.

Kingdom → Phylum → Class → Order → Family → Genus → Species

This arrangement works like an address. Just as a house address helps us locate a place exactly, classification helps scientists identify, compare and study organisms accurately, and understand how they are related.



Tiger	
Kingdom	*Animalia*
Phylum	*Chordata*
Sub-phylum	*Vertebrata*
Class	*Mammalia*
Order	*Carnivora*
Family	*Felidae*
Genus	*Panthera*
Species	*P. tigris*



Pea	
Kingdom	*Plantae*
Phylum	*Magnoliophyta*
Class	*Magnoliopsida*
Order	*Fabales*
Family	*Fabaceae*
Genus	*Pisum*
Species	*P. sativum*

Fig. 12.17: Pyramids showing levels, from kingdom at the top to species at the base, with the examples of a tiger and a pea plant

12.8 Scientific Naming — The Binomial System

A tiger is called *bagh* in Hindi, or *puli* in Tamil, tiger in English and *tigre* in French. If people from different regions discuss this animal, confusion may arise. To avoid this, scientists use a universal system of naming living organisms called binomial nomenclature. This system was introduced by Carolus Linnaeus in the 18th century. According to this, every organism has a scientific name with two parts, written in Latin or a Latinised form (Table 12.3).

Table 12.3: Scientific names of organisms in the binomial system of nomenclature

S. No.	Common name	Scientific Name
1.	Tiger	*Panthera tigris*
2.	Mango	*Mangifera indica*

Fig. 12.18: Example illustrating a scientific name

The first word, *Panthera* or *Mangifera*, is the name of the genus and the second, *tigris* or *indica*, is the name of the species. A genus groups closely related species that share common features, in this case, *Panthera tigris* (tiger) and *Panthera leo* (lion) under the genus *Panthera*—the roaring cats (possessing the ability to roar), have similar skull structure, and so on. The species name indicates a group of organisms that consists of similar individuals capable of interbreeding and producing offsprings. Together, the genus and species name form a unique scientific name used worldwide.

Rules for writing the scientific names

1. The name has two parts— genus and species.
2. The genus name begins with a capital letter and comes first, followed by the species name, which is written in small letters (lower case).
3. The scientific name is written in italics when printed, or underlined when handwritten (Fig. 12.18).

Ready to Go Beyond

The five kingdom classification offered a more comprehensive way to group organisms compared to the previous systems, but it still could not fully explain the diversity of life. Latest advances in genetic research aided in modifying this classification. With advances in microscopes and genetic studies, scientists began to compare organisms at the DNA level. As you have studied in Chapter 2, [Next Level Up] every living cell contains genetic material (DNA), which carries the instructions for its growth and function. Organisms with similar DNA are considered to have a common ancestry. Based on the genetic data, Carl Woese (1977) proposed the three domain system (Fig. 12.19)—

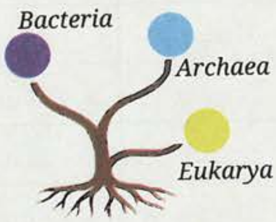


Fig. 12.19: Three domains of life

- Bacteria
- Archaea
- Eukarya

This system showed that microscopic life forms are far more diverse than previously believed.

Threads of Curiosity

Why do classification systems keep changing? Does that indicate how science works? Yes, science evolves and progresses as we learn new things. For example, Aristotle's system worked for his time, but with new tools (like microscopes) and technological advancements (like staining techniques), scientists discovered microorganisms. These discoveries helped us understand the natural world better. Accordingly, the biological classification changed. The biological classification (and science) thus, is an ongoing process of reasoning and change.

12.9 Fossils as Evidence

When we talk of diversity changing over time, what evidence do we have? Fossils are preserved remains of plants and animals found in layers of rocks, sand and mud. Generally, older layers contain simpler organisms, while newer layers show more complex forms. From giant dinosaurs to early humans and ancient plants, some important fossils have been discovered in India. Fossils act as natural records that help us understand how life has changed over millions of years.

12.10 Biodiversity Under Threat

Each species, large or small, plays an important role in nature. Plants produce food and oxygen, animals pollinate flowers and disperse seeds, and microorganisms recycle nutrients. Human activities, such as pollution, deforestation, the overuse of resources and climate change are reducing biodiversity. When one species disappears, others that depend on it may also decline in number and eventually also, disappear.

Meet a Scientist

Birbal Sahni was an eminent scientist who studied fossil plants. He founded the Birbal Sahni Institute of Palaeosciences (BSIP) in Lucknow, which continues his work on ancient plants and past environments even to this day. His studies helped link present-day plants with their ancestors and showed that life on the Earth has a long, connected history. His work continues to inspire young scientists to explore how fossils reveal the story of our planet.

Pause and Ponder

7. Does the term 'biodiversity' relate only to the variety of organisms, or does it encompass other elements?
8. If you find a new organism in a pond, what features will you observe to classify it and why?
9. Why do genetic studies provide deep information about living beings?
10. How can changes in climate affect the biodiversity?

Threads of Curiosity

When scientists discover a new organism, they compare it with the already known species. Sometimes, the species name reflects their place of discovery, or honours a scientist. The Purple Frog (*Nasikabatrachus sahyadrensis*) from Kerala has a species name after the Sahyadri Hills (Fig. 12.20).

The Purple Frog lives underground for most of the year and comes out only during the monsoon to breed. It belongs to an ancient family of frogs as understood from fossils. Its discovery in 2003 helped scientists understand ancient amphibian groups and highlighted the need for biodiversity conservation in the Western Ghats.

Fig. 12.20: A purple frog resting on wet soil

Bridging Science and Society

Floating grasslands, locally known as *phumdis* are classified as one of the unique habitats in the world. It is located in the Loktak lake of the Keibul Lamjo National Park, in Manipur, India. These floating beds of soil have a variety of rooted vegetation growing with rich organic matter in it. Its thickness varies from a few centimetres to two metres. The habitat supports an association of unique vegetation and is home to an endangered variety of *Sangai*, the dancing deer, endemic to Manipur. The deer spends considerable time on *phumdis* restricted to this small area. This deer species was declared extinct in 1951. In 1953 the deer species was rediscovered, with the efforts of naturalists based on their unique characteristics of having hooves and elongated patterns. These characteristics of the deer species helped in their identification. Recently, the *phumdis* are degenerating and the *Sangai* deer is listed in the IUCN Red Data list. Habitat loss will significantly affect the *Sangai* population. Efforts for the conservation of *phumdis* and the *Sangai* deer are currently in progress. Provide your suggestions to save habitat and the *Sangai* deer.

At a Glance

- Life on the Earth exists in many forms, from simple bacteria to complex animals.
- Scientists classify organisms based on the cell structure, number of cells, mode of nutrition and the organism's ecological role.
- Whittaker's five kingdom classification system—Monera, Protista, Fungi, Plantae and Animalia—is a simple and useful system to understand diversity.
- Kingdom Plantae is further divided into five classes—Thallophyta, Bryophyta, Pteridophyta, Gymnosperm and Angiosperm.
- Kingdom Animalia is divided into non-chordata (invertebrates) and chordata (vertebrates) on the basis of formation of notochord. Non-chordata (Invertebrates) has been divided into phyla—Porifera, Cnidaria, Platyhelminthes, Nematoda, Annelida, Arthropoda, Mollusca, Echinodermata.
- Protochordates show a transition from invertebrates to vertebrates as they possess notochord atleast once in their life. Vertebrates are further divided into groups—fish, amphibians, reptiles, birds and mammals.
- Classification is not just about naming organisms. It helps us understand the relationships among organisms, trace the history of life on the Earth and conserve the biodiversity.

Revise, Reflect, Refine

1. Meena and Hari observed an animal in their garden. Hari called it an insect while Meena said it was an earthworm. Choose the correct option which confirms that it is an insect.
   (i) Bilateral symmetrical body
   (ii) Body with jointed legs
   (iii) Cylindrical body
   (iv) Body with little segmentation
2. Sponges represent one of the simplest animal body plans. Their bodies lack true tissues and organs. Which feature of sponge cells supports its classification under the animal kingdom?
   (i) Absence of mitochondria
   (ii) Ability to photosynthesise
   (iii) Presence of a cell membrane
   (iv) Presence of a cell wall
3. Observe two different animals in your immediate environment. What features help you distinguish between them? How do these features help place them into different groups?
4. How would a scientist justify choosing cellular organisation as a more fundamental characteristic for the basis of classification rather than the presence of xylem and phloem?
5. You find an unlabelled slide of a single-celled organism that has a well-defined nucleus and multiple cilia. Which group would it most likely belong to? Give reasons.
6. How does the diversity of organisms contribute to the balance and stability of an ecosystem?
7. If all unicellular organisms were grouped into a single kingdom, what problems would arise?
8. Viruses were studied in earlier classes. Why are they not placed in any of the five kingdoms? Give reasons.
9. If you were asked to revise the five kingdom classification, would you create a separate category for viruses or keep them outside the system? Justify your answer and explain what this indicates about the evolving nature of scientific classification.
10. Viruses contain genetic material like living organisms but lack cellular organisation. Which features prevent them from fitting into the five kingdom system? What does this tell us about the limitations of classification systems?
11. Both pteridophytes and bryophytes lack flowers and seeds, yet they are placed in different groups. Explain this classification using their key features.

12. In the classification hierarchy, which group — class or genus — has fewer members but more features in common? Explain your answer.
13. A scientist discovers a new organism with the characteristic features of locomotion and autotrophic nutrition. Which character(s) would help the scientist identify the organism belonging to Protista according to the five kingdom classification?
14. A researcher identified a unicellular eukaryotic organism as fungi. What identification key would you suggest according to the five kingdom classification to keep a unicellular organism in the Kingdom Fungi?
15. During a long-term ecological study, students examined organisms collected from three different environments — a freshwater pond, damp soil near decaying logs and the digestive tract of animals. Instead of naming organisms directly, scientists recorded only structural, cellular and nutritional features as given in the table below.

Organisms	Key Observations
P	Microscopic; no true nucleus; rigid cell covering; survives high salinity and temperature
Q	Multicellular; filamentous body; cell wall present; no chlorophyll; grows on dead organic matter
R	Unicellular; true nucleus; contractile vacuole present; moves using flagella; shows photosynthesis in light but heterotrophic in the absence of light
S	Multicellular; well-differentiated tissues; backbone present; aquatic respiration during early life stage
T	Acellular; contains genetic material; remains inactive outside a host cell

The students realised that some organisms fit neatly into Whittaker's five kingdom classification, while others challenged the very basis of this classification.

Based on the case study, answer the following questions —

(i) Identify one organism that clearly belongs to the Kingdom Fungi. State one observation that supports your answer.

(ii) Which organism would be placed in the Kingdom Monera? Mention one characteristic that justifies this placement.

(iii) Organisms R and Q are both eukaryotic, yet they are placed in different kingdoms. Analyse the criteria that separate them.

(iv) Explain why organism S cannot be classified using the mode of nutrition alone.

(v) Organism T does not fit into any of the five kingdoms. Which fundamental characteristic used in classification does it lack and what does this reveal about the limitations of classification systems?

(vi) If classification were based only on habitat, which organisms might be incorrectly grouped together? Explain the scientific consequences of such a classification.

(vii) Imagine scientists discover a new organism that is multicellular, eukaryotic, lacks chlorophyll and absorbs nutrients from a host externally. Should it be placed under fungi or animalia? Justify your reasoning using classification criteria.

The Journey Beyond

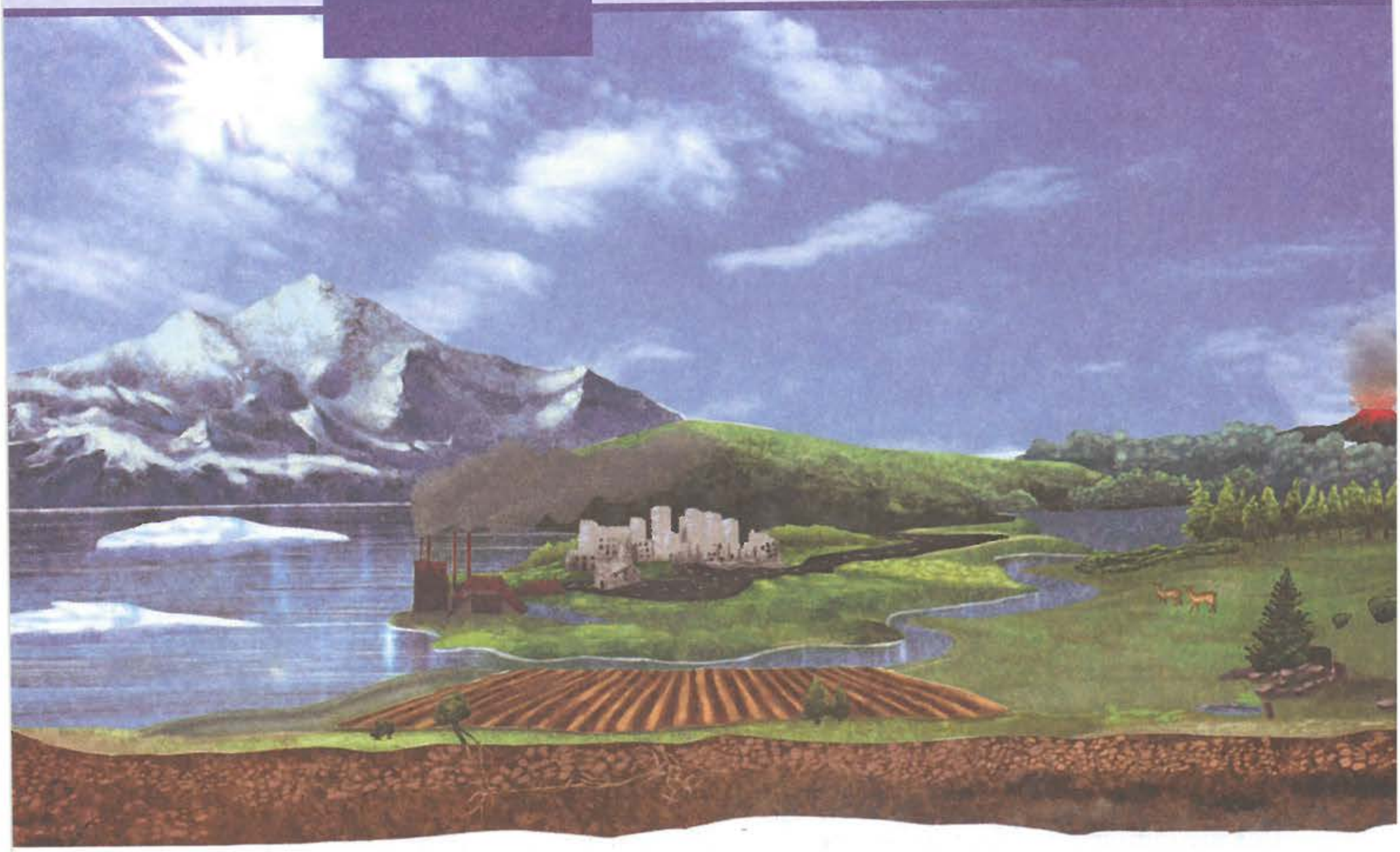
- Visit a nearby park or a water body. Observe the water body and its surroundings. Identify ten organisms and classify them into kingdoms.
- Interview a gardener or a forest worker. Ask them how they identify species. Compare the traditional scientific methods of identification.
- If you were studying the Pakke Tiger Reserve or any other bird sanctuary of your choice, how would you organise the information about the bird species?
- Conduct a survey in a forest area near a village, identify edible and poisonous mushrooms with the help of indigenous knowledge of community resource person(s).
- Collect and study the postal stamps of India and the world released over time on diversified flora and fauna. Based on your learning, make your own criteria and classify them. Organise a philately (collection of postage stamps) exhibition in your school and showcase your work in this exhibition.
- Investigate an extinct species and analyse how its disappearance impacted the organisms that depend on it, and how this affected the ecological balance of the ecosystem.
- Study the diversity of farm animals used in different types of farming practices in various parts of the country.

The Quest Continues...

What knowledge do you think scientists would come up with further and how would it affect the classification system?

Chapter 13

Earth as a System: Energy, Matter, and Life



Think It Over

- How does the warming of Arabian Sea water affect the southwest monsoon in India?
- If a large forest is cleared, how can that affect the flow of a river in that area?
- What might happen to coastal cities in India if glaciers and polar ice keep melting faster?
- How would increasing carbon dioxide levels in the atmosphere affect the ocean plankton?

Life on Earth is powered by a constant flow of energy and matter. The Sun is the main source of energy. In addition, the Earth's hot interior and chemical reactions in the air, water, and rocks also drive the flow of energy and matter. During the middle stage in *Curiosity* (Grades 6 – 8) and in earlier chapters of this textbook, you explored these ideas as separate content pieces. For example, you learnt how sunlight drives winds and the water cycle; how plants and microbes cycle nutrients; how the Earth's tilt causes seasons; and how human activities are modifying air, water, soil and climate. In this chapter, we will consider these processes together as belonging to one Earth system made up of interacting 'spheres' —

- **Geosphere:** Solid rocks, soil, landforms (like the Deccan plateau and the Thar desert), and the Earth's interior.
- **Hydrosphere:** Liquid water in the form of surface water, such as oceans, rivers (like the Ganga – Brahmaputra river system), lakes and groundwater.

- **Cryosphere:** Solid form of water, such as ice and snow (like the Himalayan glaciers, snow in Ladakh and polar ice caps).
- **Atmosphere:** The air surrounding the Earth that we breathe (cleaner air in the mountains and forests).
- **Biosphere:** All living organisms and their habitats (including mangroves, forests, farms, ocean plankton and coral reefs).

We will explore how energy and matter move, interact across the Earth's spheres, and how a change in one affects others. Understanding these processes has been an important part of the continuing journey of the exploration of science. Natural processes, such as heating by solar radiation, movement of air and water, and nutrient cycling connect these spheres in a delicate balance. Let us understand this by conducting Activity 13.1 and explore how different spheres on the Earth continuously interact with each other.

Activity 13.1: Let us explore

1. **Observe** the features of the Earth as shown in Fig. 13.1. **Identify** and circle one example representing each of the geosphere, hydrosphere, cryosphere, atmosphere, and biosphere.
2. How does snow (cryosphere) eventually become part of the lake (hydrosphere)?
3. If there is less snowfall during winters for a few years, how would this affect the lake's level and the grass available for the sheep?
4. Discuss with your classmates and write down how all the spheres are interconnected, and how a disturbance in one can lead to changes in others.

Fig. 13.1: Some features of the Earth's surface

From Activity 13.1, we can **infer** that a disturbance in one sphere can lead to changes in others. For example, less snowfall in winters may lead to less water in the lake in summers, resulting in less water to support the growth of grass. Similarly, on a large scale, warmer Arabian Sea water lead to more evaporation from the sea. This in turn, causes fluctuations in the southwest monsoon, which results in variability in rainfall, bringing floods to some regions of India while leaving others in drought. This disrupts the hydrosphere. At the same time, the rise in atmospheric temperature could eventually accelerate the melting of glaciers and polar ice in the cryosphere, which may lead to the flooding of low-lying regions, and in the long run, it can raise sea levels that may threaten coastal cities. This could disturb the ecosystems within the biosphere by causing a habitat loss.

Does the solar radiation heat the Earth's surface evenly? Let us explore how solar radiation varies from the equator to the poles, the oceans to the mountains, and drives many of Earth's natural processes, such as wind, ocean current, water cycle, etc.

13.1 Uneven Heating of the Earth

Solar radiation is the main source of energy on the Earth. It reaches the Earth as **electromagnetic (EM) waves** that travel through a vacuum at the speed of light (unlike EM waves, sound waves, which you studied in Chapter 10, Sound Waves: Characteristics and Applications, are mechanical waves and require a medium to travel). The speed of light in vacuum is 3×10^8 ms^{-1}. EM waves cover a wide range of frequencies, from high frequency or short wavelength radiation (**gamma rays** and **X-rays**) to low frequency or long wavelength radiation **(infrared** and **radio waves)**. The high frequency EM waves, such as gamma rays and X-rays have very high energy and can be harmful for life on Earth.

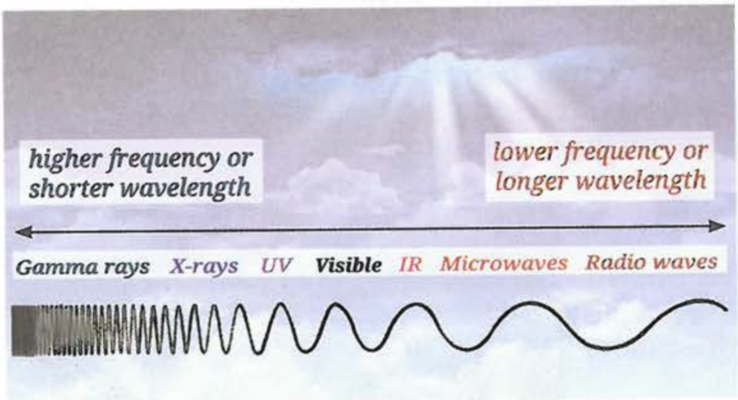


Fig. 13.2: Electromagnetic spectrum

The entire range of electromagnetic radiation called **electromagnetic spectrum** is shown in Fig. 13.2. However, the solar radiation reaching Earth is concentrated mainly in the ultraviolet (UV), visible and infrared (IR) range—about 99 per cent of the Sun's energy falls within these wavelengths. These three regions of the spectrum shape the Earth's climate and support life. Gamma rays and X-rays are mostly filtered by the Earth's upper atmosphere, while microwaves and radio waves carry very little energy to significantly warm the Earth.

Short wavelength UV radiation is mostly absorbed by the ozone layer in the upper atmosphere, protecting life and contributing to some atmospheric heating. Visible light from the Sun reaches the Earth's surface and provides energy for photosynthesis, which is the primary source of food for most organisms. It also partly warms the land and water. Infrared radiation warms the Earth's surface, which then re-radiates this heat back into the atmosphere. A portion of this outgoing heat is trapped by the greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4) and water vapour, keeping the Earth warm enough to support life.

Ready to Go Beyond

The UV rays lie in the wavelength range of 100 nm to 400 nm [1 nanometre (nm) = 10^{-9} m] and have a much higher energy than the visible light. Prolonged exposure to these rays can damage the eyes and skin, and increase the risk of cancer. Therefore, people should use UV protective glasses and sunscreen if they are likely to be exposed to UV rays. UV rays are also useful in killing germs in water purifiers and help power fluorescent lights.

The amount of the Sun's radiation that reaches the Earth's surface is called **insolation**. It is responsible for warming the Earth's surface and its atmosphere. The average amount of solar energy received per unit time per unit area that is perpendicular to the Sun's rays at the top of the Earth's atmosphere is called the **solar constant**. Its value is approximately 1.4 kilowatts per square metre (1.4 kWm^{-2}), or about 1400 joules per second per square metre (1400 J $s^{-1}m^{-2}$). It represents the Sun's energy available on the Earth before any absorption, scattering or reflection occurs in the atmosphere.

The solar constant is important because it helps scientists understand the Earth's energy balance, climate and weather patterns. However, some of this energy is absorbed and scattered by gases, clouds and dust particles in the atmosphere before reaching the surface of the Earth. As a result, the maximum insolation reaching the Earth's surface is lower than the solar constant and is about 1 kWm^{-2} under clear sky conditions. India, due to its geographical location in the tropical and sub-tropical regions, receives abundant sunlight throughout the year. This makes solar insolation highly significant as it drives the southwest monsoon, which influences India's climate and agriculture. It also offers immense potential for harnessing solar energy as a renewable and sustainable source of energy.

Bridging Science and Society

Anna Mani, India's pioneering atmospheric scientist, mapped solar insolation across India in the 1950s. She later published ***Solar Radiation Over India*** in 1981, creating the country's first **insolation atlas**. Her pioneering measurements showed India's vast solar energy potential. Today, this is being realised through the large-scale deployment of solar power across the country. India is laying the foundation for a resilient, sustainable and solar-powered energy future that sets global benchmarks.

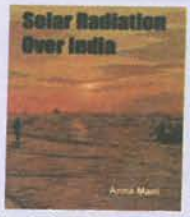


Fig. 13.3: Solar Radiation Over India, a book by Anna Mani

Example 13.1: How much solar energy will be received by a 1 m^2 area in one hour, if the insolation on the surface of the Earth were 1 kWm^{-2}?

Answer: E = Intensity × area × time

$E = 1 \times 1000 \ J\,s^{-1}\,m^{-2} \times 1\ m^2 \times 3600\ s$

$E = 3600000\ J = 3.6 \times 10^6\ J$

(This amount of energy is approximately equal to the energy needed to melt 5 kg of ice and heat the water obtained to 100 °C. It is also equal to one unit of electricity used in a household, as shown on an electricity bill).

Think as a Scientist

An interesting estimation problem that helps us to appreciate the enormous amount of energy that we get from the Sun is to estimate how much of the Earth's surface would be needed to be covered with solar panels to supply all the electric power that our country uses today (Fig. 13.4). To make this estimate, you can find these numbers on the internet, assume some insolation on the Earth's surface and consider that some fraction of this energy is converted into electricity. You will probably find that even a fraction of the area of the Thar desert, if covered with solar panels, could supply India's electricity needs.

Fig. 13.4: Solar panel in the desert

How does the Sun's radiation interact with the Earth's surface and atmosphere, and warm the Earth? We will discuss more about it in the following sections.

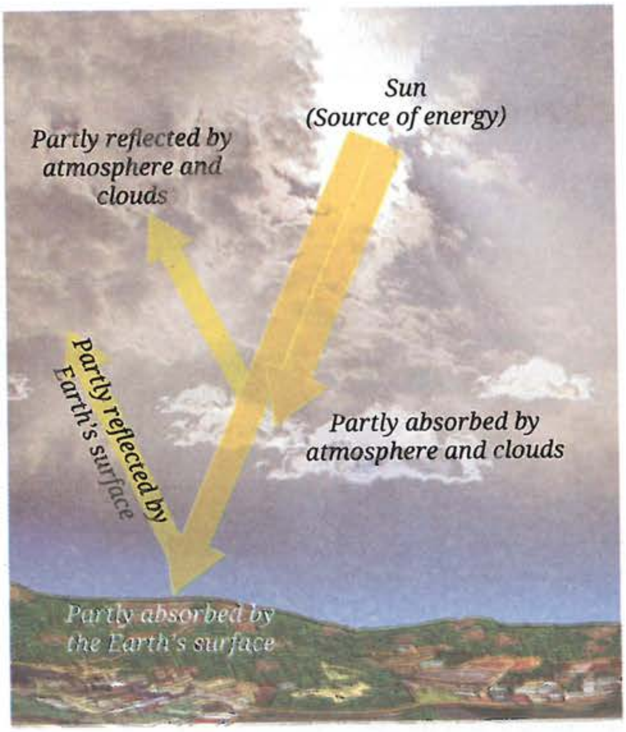


Fig. 13.5: Solar radiation and warming of the Earth

13.1.1 Interaction of solar radiation on the Earth's surface

Different materials absorb and heat up differently under sunlight. You have already learnt how land heats up faster than water. There may be some variation due to the material forming the land and the colour of the soil. Dark surfaces absorb more sunlight, while light coloured surfaces reflect more and remain comparatively cooler. For example, dark coloured roads heat up more quickly, while light coloured surfaces remain comparatively cooler. You have also learnt why dark coloured clothes feel hotter than white ones in summer.

Grade 7 Curiosity Chapter 7

The fraction of solar radiation reflected by a surface is called its **albedo** (the word 'albedo' comes from Latin which means whiteness). High albedo surfaces stay cool because they reflect more light, while low albedo ones heat up more quickly as they reflect less and absorb more light (Fig. 13.5). Let us try to find out the albedo of some of the common objects we come across in our daily lives by conducting Activity 13.2.

Activity 13.2: Let us find out

Complete Table 13.1 using information from authentic sources like websites and books.

Note

Ensure that you do not share any personal information while using the internet.

Table 13.1: Reflection of solar radiation by surfaces of materials

S. No.	Materials	Albedo
1.	Snow	0.80 – 0.90
2.	Ice	0.50 – 0.70
3.	Crushed rock	0.25 – 0.30
4.	Light coloured soil	
5.	Black soil	
6.	Ocean water	

From Table 13.1, you must have seen that snow and ice have high albedo, meaning they reflect a large proportion of the incoming solar radiation. This makes polar regions very cold. On the other hand, surfaces like black soil and ocean water have lower albedo as they absorb more solar radiation, and hence, they are relatively warmer.

You have also learnt in the earlier grades that all objects radiate heat. We feel hot inside a concrete house at night especially during hot summer, this is due to the heat re-radiated by the concrete during the night. However, traditional houses built with thick mud and wooden walls offer cool conditions even in hot summer due to less re-radiation.

Grade 7 Curiosity Chapter 7

Threads of Curiosity

Urban Heat Island Effect

Cities are warmer than their surrounding rural areas, especially during summer and at night. Compared to rural areas, cities have more built-up areas, including buildings of steel, concrete, brick, and roads made up of concrete and asphalt. All these materials absorb solar radiation and retain heat. The re-radiated heat from these materials warms cities more than the surrounding rural areas. This increases energy demand for air conditioning further stressing the urban ecosystems. Rural areas and forests have more vegetation, and stay cool through shade and plant transpiration. The urban heat island effect shows how human land use can alter the local climate (Fig. 13.6).

Fig. 13.6: Urban heat island effect in a city

The amount of radiation received by a particular region on the Earth's surface also depends on its latitude. The uneven heating due to the latitude of a place is important as it determines the atmospheric conditions of that place.

13.1.2 Latitude and Earth's shape

You have already learnt in earlier grades that the Earth is spherical. As a result, the Sun's rays strike different latitudes at different angles on the Earth. The Sun's radiation falling on the equatorial region is concentrated over a smaller area, where it is spread over a larger area in the polar region. This is why, equatorial regions remain relatively warm throughout the year, whereas polar regions experience much colder conditions. This uneven heating creates temperature differences between the equator and the poles.

Grade 7 Exploring Society: India and Beyond Part 1 Chapter 3

You have also learnt how the Earth's spherical shape and the tilt of the Earth's axis of rotation give rise to seasons, and the changing length of daytime during one revolution of the Earth around the Sun. Thus, solar radiation is not evenly distributed across the globe. This uneven heating of the Earth's surface across the globe drives global winds and ocean currents.

Grade 7 Curiosity Chapter 12

13.1.3 Role of the atmosphere

The air surrounding the Earth is called atmosphere. It is held in place by the force of Earth's gravity. It consists mainly of nitrogen (78%) and oxygen (21%) along with small amounts of argon, carbon dioxide, water vapour, and other gases.

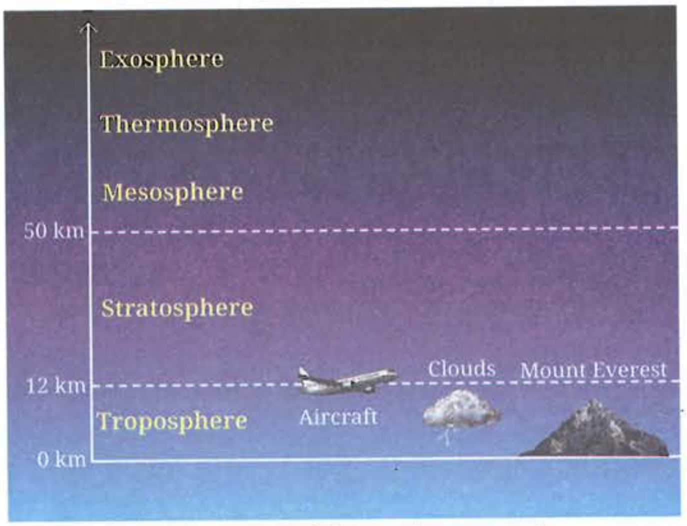


Fig. 13.7: Layers of the Earth's atmosphere

The Earth's atmosphere has a layered structure. This structure of the atmosphere is important as it helps explain key weather patterns (Fig. 13.7). Nearly, all weather phenomena take place in the troposphere (with an average height of about 12 km), which is heated from the Earth's surface. In this layer, temperature decreases with height (~6.5 °C/km). As the warm air rises, it drives winds and storms. The height of the troposphere is maximum above the equator and lowest above the polar regions.

In the stratosphere (12 – 50 km), where the ozone layer is located, ozone absorbs UV rays and heats up the atmosphere, so temperature rises with height. This increase in temperature with height in the stratosphere calms the layer due to the lack of vertical mixing of air, keeping weather confined to the troposphere. Above the stratosphere are the mesosphere, thermosphere and exosphere, but they play only a minor role in regulating climate on the surface of the Earth. At about 100 km above the Earth is the start of the region, we call the outer space. These atmospheric layers show how the atmosphere regulates energy flow, shaping weather, climate and life.

Table 13.2: Key atmospheric layers

Layer	Approximate altitudes	Features
Troposphere	0 – 12 km	Weather formation; temperature decreases with height
Stratosphere	12 – 50 km	Ozone layer absorbs UV; temperature increases with height

The atmosphere plays two crucial roles in protecting the life on the Earth. Firstly, it partly absorbs the incoming solar radiation. The ozone layer blocks the harmful UV rays. Clouds and other gases also absorb some sunlight before it reaches the surface of the Earth (Fig. 13.5). Secondly, it traps outgoing heat. The Earth's surface absorbs sunlight and re-radiates it in the infrared region. Greenhouse gases like CO_2, CH_4 and water vapour absorb this re-radiated heat, preventing it from escaping into space. Without the atmosphere, the Earth would be too cold for life to survive. However, excess CO_2 from human activities enhances the greenhouse effect, causing global warming, which if left unchecked could make the Earth uninhabitable.

You have also learnt that Venus is hotter than Mercury, even though Mercury is closer to the Sun. This is because of the presence of an atmosphere on Venus, which has led to an uncontrolled greenhouse effect.

Grade 8 Curiosity Chapter 13

Meet a Scientist

K.R. Ramanathan, India's atmospheric scientist, climbed to an altitude of 18,000 feet in the Himalayas in 1934 to measure the ozone levels, and discovered that they were lower than expected. His work laid the foundation for understanding how UV absorption varies with altitude and pollution. Later on, he led early monsoon forecasting efforts.

Pause and Ponder

1. Visit the website given below and study the effect of the concentration of greenhouse gas on surface temperature, https://phet.colorado.edu/en/simulations/greenhouse-effect

The atmosphere is continuously modified by natural processes, influencing weather, climate and energy balance. When solar radiation and cosmic rays interact with the atmosphere, they influence weather and climate, and affect communication systems. Thus, atmosphere makes the Earth a unique planet.

Threads of Curiosity

Why is the ozone layer so important?

The ozone layer is vital to life on the Earth because it acts as a protective shield, absorbing harmful UV radiation from the Sun. When ozone molecules are destroyed faster than they are naturally formed, the layer becomes thinner and less effective. In the late 20th century, human-made chemicals called chlorofluorocarbons (CFCs), used in refrigerators and aerosols, caused severe ozone loss over Antarctica, which came to be known as the ozone hole. Increased UV radiation on the Earth can harm the living organisms and the ecosystems. A global agreement known as the Montreal Protocol reduced the use of CFCs and the ozone layer is now slowly recovering, showing the power of international scientific cooperation.

13.2 Uneven Heating Causes Wind and Ocean Currents

You have learnt that wind is the movement of air from a region of high pressure to a region of low pressure. These pressure differences are mainly caused by the uneven heating of the Earth's surface by the Sun. Uneven heating of land and water is also responsible for phenomena, such as land and sea breezes, which you have studied earlier. The same basic idea helps us understand the formation of winds and ocean currents on vastly different scales.

Grade 8 Curiosity Chapter 6

13.2.1 Local winds

Uneven heating of the Earth's surface also produces **local winds**, such as valley and mountain breezes. In mountainous regions, the slopes and the valley floor do not heat up and cool down at the same rate. During the day, the mountain slopes facing the Sun are heated more rapidly than the valley floor. As a result, the air over the slopes becomes warm and rises, creating a low pressure region. Cooler air from the valley moves up the slopes to replace the rising warm air. This flow of air is called a **valley breeze** (Fig. 13.8a).

Fig. 13.8 (a): Valley breeze

After sunset, the situation reverses. The mountain slopes lose heat faster and become cooler, while the valley floor remains relatively warmer. The air over the slopes becomes cooler and denser, and flows down into the valley. This is known as a **mountain breeze** (Fig. 13.8b). Such daily changes in the direction of the wind are commonly experienced in hilly regions like Shimla, Dehradun, and other Himalayan valleys. These local winds influence the weather conditions, agriculture and daily life in mountainous regions. They help regulate temperature, moisture conditions and support soil and crop health. Thus, uneven heating of the Earth's surface sets up winds and forms an important part of the Earth's atmospheric circulation.

Fig. 13.8 (b): Mountain breeze

13.2.2 Planetary winds

Uneven heating of the Earth between the equator and the poles create belts of low and high pressure. This large scale pressure difference sets the air in motion over long distances, giving rise to **planetary winds**.

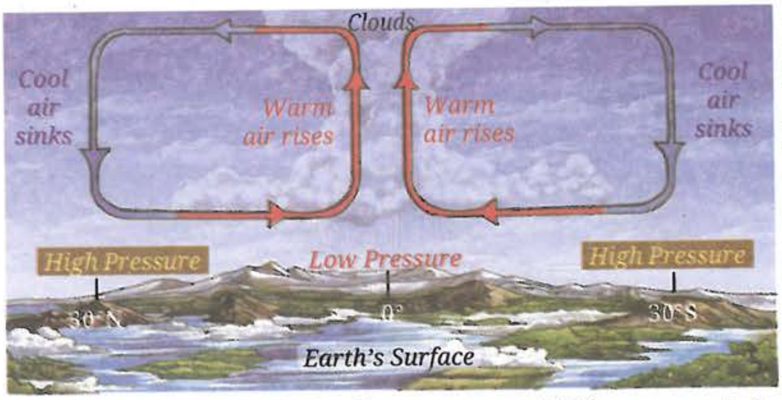


Fig. 13.9 (a): Wind circulation between equatorial low pressure belt and sub-tropical high pressure belt

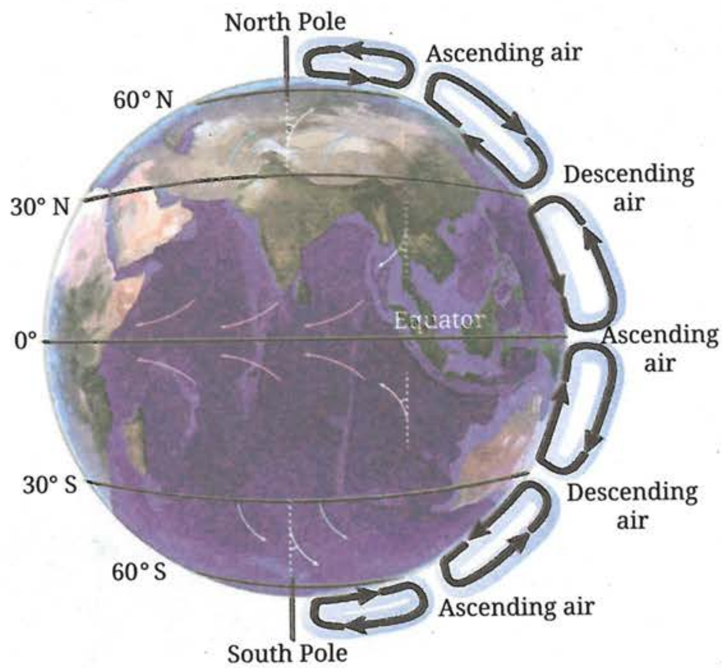


Fig. 13.9 (b): The distribution of pressure belts and planetary winds

Near the equator, intense heating by the Sun causes warm air to rise, forming an equatorial low pressure belt. As this air rises, it moves poleward at higher altitudes. On cooling, it becomes denser and sinks around 30° North and South latitudes, forming the sub-tropical high pressure belts. From these high pressure regions, air flows back towards the equator along the Earth's surface, completing one circulation cycle (Fig. 13.9a). However, not all the sinking air at the sub-tropical belt returns to the equator. A part of it moves towards the poles along the surface, and rises again around 60° North and South latitudes, where it meets the cold air from the polar regions. This creates the sub-polar low pressure belts.

In the polar regions (around 90° North and South), very low temperature causes cold and dense air to sink, forming polar high pressure belts. Air from these regions flows towards the sub-polar belts, completing another circulation cycle (Fig. 13.9b). The Earth's rotation causes these winds to be deflected from their straight paths. As a result, planetary winds follow curved paths rather than moving directly from high pressure to low pressure regions. The winds are deflected towards the right in the Nothern Hemisphere and towards the left in the Southern Hemisphere due to the rotation of the Earth on its axis.

13.2.3 Ocean currents

Ocean currents are the continuous movement of large masses of ocean water. Similar to winds, planetary pressure differences also drive the ocean currents. Strong planetary winds drag the surface water of the oceans because of friction, setting surface currents in motion. In addition to winds, differences in temperature and salinity, the rotation of the Earth, and the distribution of land masses influence the movement of ocean water. The water of the equatorial and the polar regions have different temperatures. While warm equatorial waters travel over the surface toward the poles, colder and denser waters slowly flow back towards the equator through deeper ocean levels. Ocean water has different salinities depending on the location. Water with lower salinity, being less dense, tends to remain near the surface, while higher salinity, denser water sinks and moves at deeper levels in the ocean. The Earth's rotation deflects these moving water masses, forming large circular patterns called **gyres**. These rotate clockwise in the Northern Hemisphere and counter clockwise in the Southern Hemisphere (Fig. 13.10a). Continents further modify these paths by blocking and redirecting currents.

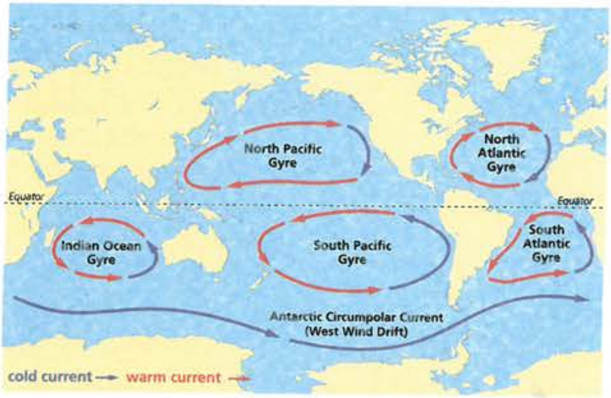


Fig. 13.10 (a): Global surface ocean currents showing circulation like gyres

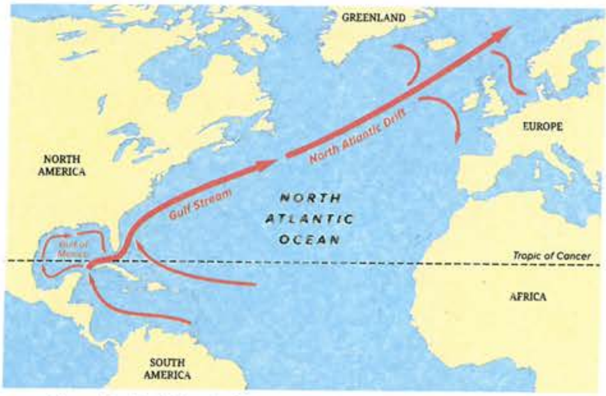


Fig. 13.10 (b): Gulf Stream brings warm water from the equator

Ocean currents play a major role in regulating the Earth's climate and supporting life. By transporting heat from the equator towards the poles, they reduce temperature differences across the planet. For example, the warm ocean current—the North Atlantic Drift (Fig. 13.10b), an extension of the Gulf Stream (a strong ocean current carrying warm water from the southern part of the North American east coast across the Atlantic Ocean)—flows toward the northwestern coast of Europe and keeps many ports ice-free during winter, even at high latitudes. This moderating influence on climate also supports human activities, such as trade and commerce. Ocean currents also support a massive ecosystem by transporting nutrients.

Pause and Ponder

2. How does the cool mountain breeze benefit agriculture activity, particularly the crops and soil?
3. What happens to the warm surface of water from the equator as it travels toward the poles? What impact does this movement have on the area?

India's Scientific Contributions

Scientists at the Indian Institute of Tropical Meteorology (IITM), Pune, run advanced computer models that couple the energy flows we discussed in this chapter, between atmosphere, oceans, land and ice to simulate the Indian monsoon. These models use data from satellites, buoys in the Indian Ocean, and even stations in Antarctica to improve seasonal forecasts and to study how global warming may change monsoon rainfall patterns across India.

Fig. 13.11: Indian Institute of Tropical Meteorology (IITM), Pune

13.3 Biogeochemical Cycles

Living organisms constantly exchange matter and energy with the air, water, soil and rocks around them. This continuous interaction between the non-living (abiotic) and living (biotic) components of the Earth results in the transfer of matter and energy across various spheres of the Earth, as discussed earlier. This process ensures that essential nutrients, such as carbon, nitrogen and oxygen are recycled, and remain available to support life on the Earth. This cyclic movement of matter and energy between the abiotic and biotic components is called the **biogeochemical cycle**. There is a dynamic relationship between different ecosystems. This interconnectedness helps ecosystems recover from disturbances or degradation and maintain environmental balance.

We will examine the water, carbon, nitrogen and oxygen cycles. We will try to understand why their balance matters, and explore how they interconnect across spheres and respond to human impacts.

13.3.1 Water cycle

Grade 7 Curiosity Chapter 7

You have studied the water cycle and learnt terms like evaporation, transpiration, condensation, precipitation, infiltration and groundwater. The water cycle is summarised in Fig. 13.12. In this cycle, water evaporates from water bodies, such as rivers, lakes, oceans, etc., and condenses to form clouds. It returns as precipitation in the form of rain, hail or snow to the surface and finally flows back to the ocean. Some of the water seeps through soil and rocks beneath the Earth's surface. Water dissolves minerals from soil and rocks. It also supports all terrestrial organisms and transports these nutrients to oceans, and support marine life.

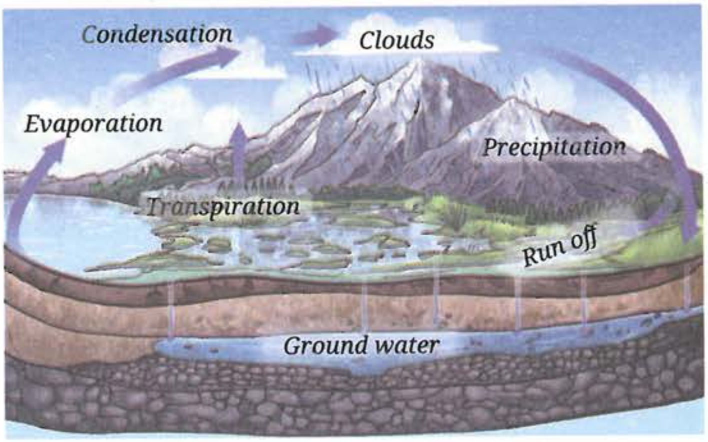


Fig. 13.12: Water cycle

Climate change is now affecting the water cycle. For example, a warmer atmosphere holds more moisture, causing heavier rains in some areas (like intensified monsoons) and droughts elsewhere. Melting glaciers add more water to rivers, raising sea levels in the long run and threatening coastal cities, such as Mumbai and Chennai. Sudden bursts of intense rainfall result in more run off that erodes soil and less infiltration reduces the recharge of groundwater, which in turn, makes sustaining agriculture difficult, especially during dry months. In this way, the water cycle links the cryosphere (glaciers), hydrosphere (rivers and oceans), atmosphere (moisture), geosphere (soil erosion and decreased infiltration), and biosphere (crops and fisheries), all of which are affected by global warming.

13.3.2 Carbon cycle

Carbon forms the backbone of life. Every protein, carbohydrate, fat and DNA molecule contains carbon. It circulates continuously between the atmosphere (CO_2 gas), biosphere (plants and animals), geosphere (carbonate rocks and fossil fuels, such as coal and oil), and the hydrosphere (dissolved CO_2 and marine shells) as shown schematically in Fig. 13.13. Different parts of the carbon cycle operate at very different time scales. In the fast cycle, which happens over days to years, plants convert atmospheric CO_2 into glucose using sunlight through photosynthesis. CO_2 is released back into the atmosphere through respiration. Animals eat plants and/or other animals. When they die, CO_2 returns to air because of decomposition.

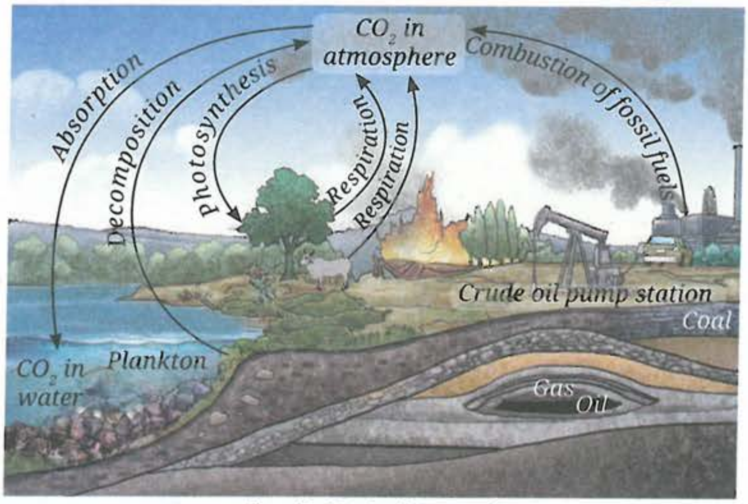


Fig. 13.13: Carbon cycle

In the slow cycle, which happens over millions of years, dead plants and animals get buried, and are converted to fossil fuels, such as coal, oil and gas. These fuels are burnt to provide energy for various needs like heating, cooking, transportation and industrial purposes. When fossil fuels are burnt, carbon is released back as CO_2 on a very short time scale. The atmosphere and ocean water continuously exchange CO_2. The ocean water absorbs atmospheric CO_2 to form carbonate and bicarbonate ions. Phytoplankton use them for photosynthesis. Some marine organisms also use them to form shells. When organisms die, they sink to the ocean floor and their organic matter is stored as carbon for a long period.

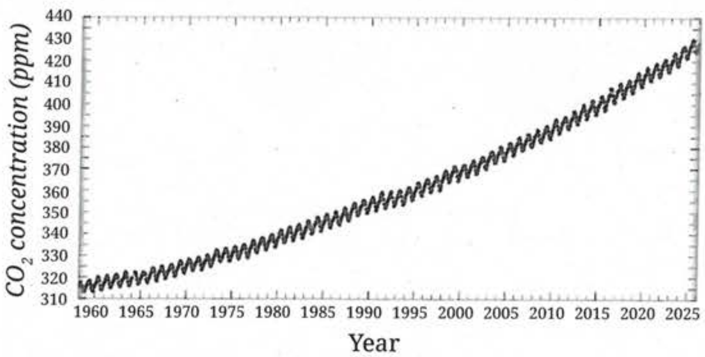


Fig. 13.14: Atmospheric CO_2 concentration (1960 – 2025), the Keeling curve. The sawtooth pattern shows seasonal dips from yearly plant growth in the Northern Hemisphere absorbing CO_2

Human activities like burning fossil fuels and deforestation have raised atmospheric CO_2 by about 35% since 1960 as shown in Fig. 13.14 (315 ppm to 420 ppm; ppm denotes parts per million), an unprecedented rise in the history of human civilisation. While some amounts of carbon dioxide are necessary to keep the Earth warm enough to sustain life, the balance is critical. Excessive amounts of CO_2 intensify the greenhouse effect leading to global warming, melting of glaciers and Arctic sea ice, rising of sea level and more extreme weather conditions. In India, this may lead to more intense monsoons (warmer air holds more moisture) and threats to agriculture from its changing rainfall patterns. Though fossil fuels still power much of our electricity generation, India is rapidly increasing renewable energy sources, which will help minimise the carbon released into the atmosphere.

Pause and Ponder

4. The CO_2 dissolved in the ocean is disturbed when the global temperature increases. What will happen to marine life?

Threads of Curiosity

Carbon constitutes ~ 49% of dry weight of living organisms. Out of the total quantity of global carbon, 71% carbon is found in oceans. This oceanic reservoir regulates the amount of carbon dioxide in the atmosphere.

Do you know that the atmosphere holds only a very small fraction (about 1%) of the total global carbon?

13.3.3 Nitrogen cycle

Nitrogen is an essential element for the synthesis of proteins and nucleic acids in all living organisms. The largest reservoir of nitrogen is in our atmosphere. However, nitrogen gas (N_2) is rather non-reactive, and cannot be directly used by plants and animals. It must first be converted to soluble compounds that living beings can absorb. The overall movement of nitrogen between air, soil, water and organisms is called the **nitrogen cycle** (Fig. 13.15). The nitrogen cycle contains several steps — nitrogen fixation, assimilation, **ammonification**, **nitrification** and **denitrification**.

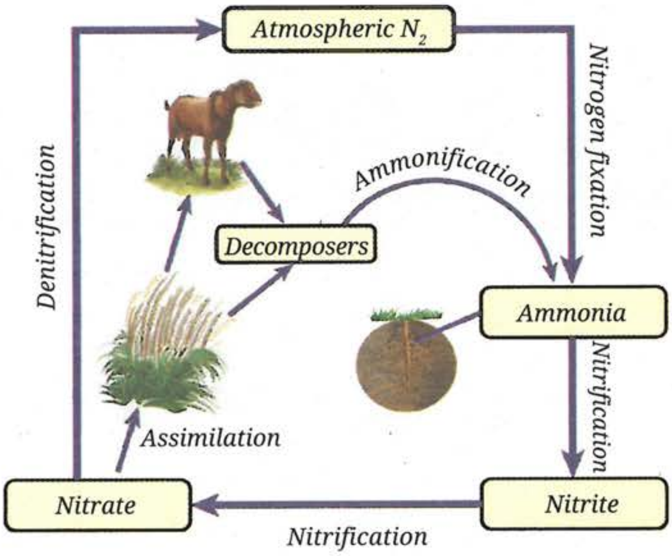


Fig. 13.15: Nitrogen cycle

Nitrogen-fixing bacteria, such as *Rhizobium* in the root nodules of legumes and *Azotobacter* in the soil, convert atmospheric N_2 into ammonia (NH_3). Nitrifying bacteria like *Nitrosomonas* convert ammonia into nitrite (NO_2^-), while *Nitrobacter* convert nitrite into nitrate (NO_3^-). This process is known as **nitrification**. Plants assimilate these nitrogen compounds from the soil, whereas animals obtain nitrogen by consuming plants or other animals. When plants and animals die or produce waste, decomposers like bacteria and fungi break the organic matter, returning nitrogen compounds like ammonia to the soil. This process is known as **ammonification**. Denitrifying bacteria, such as *Pseudomonas* convert some nitrates back into nitrogen gas. This process is known as **denitrification**. This completes the cycle and maintains a balance of nitrogen in ecosystems. Lightning also contributes to the fixation of nitrogen oxides.

Ready to Go Beyond

During lightning strikes, a tiny amount of atmospheric nitrogen is fixed to produce nitrogen oxides. Today most of the nitrogen is fixed artificially via the Haber-Bosch process (early 1900s) of making ammonia from atmospheric nitrogen, which produces most of the fertilisers used today. This 'Bread from Air' revolutionised agriculture, enabling India's Green Revolution and feeding billions. More than half the nitrogen atoms in the human body come from the Haber-Bosch process. However, this reaction is energy intensive (uses ~ 1 – 2% of global energy), and the overuse of fertilisers has degraded soil and water.

13.3.4 Oxygen cycle

Oxygen is one of the Earth's most abundant elements. About 21% of the atmosphere consist of free oxygen gas (O_2). It is an essential component of most biological molecules like carbohydrates, proteins, nucleic acids and fats. Oxygen also exists in combined forms — in the Earth's crust as metal oxides and minerals, and in the air as carbon dioxide. While discussing the oxygen cycle, we focus on processes that regulate the oxygen level in the atmosphere (Fig. 13.16). Organisms like plants and animals use oxygen for respiration, and releases CO_2. Combustion of fuels uses oxygen and releases CO_2. Plants restore oxygen through photosynthesis using sunlight, water and CO_2 to form glucose and release O_2. This balance between consumption (respiration and combustion) and production (photosynthesis) circulates oxygen between the atmosphere, land, oceans and living organisms, sustaining life across all spheres of the Earth.

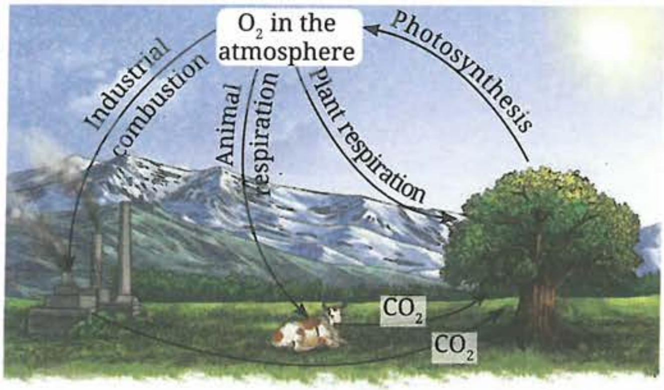


Fig. 13.16: Oxygen cycle

Pause and Ponder

5. What would happen to plants and animals on Earth if the biogeochemical cycles were disrupted and stopped? Explain by giving a few examples.

13.4 Human Impact on Earth's Processes

You have learnt about the impact of climate change earlier, in which we examined the crises our planet Earth is facing. Rising CO_2 levels from the use of fossil fuels leads to extreme weather and biodiversity loss. Here, we will examine how human actions disrupt the biogeochemical cycles across the Earth's spheres. Excess atmospheric CO_2 increases ocean absorption, making sea water more acidic. This could threaten tiny plankton and coral reefs, disrupting the marine ecosystems. However, warmer ocean water reduces the ocean's capacity to absorb CO_2 as an effective carbon sink.

Grade 8 *Curiosity* Chapter 13

Burning of fossil fuels and deforestation saturate natural carbon sinks like forests and oceans. Over the past 50 years, there has been a significant change in the Earth's natural systems. In India, fossil fuels still generate a significant part of our electricity, contributing harmful emissions, although the rapid growth of solar energy offers hope. The excess CO_2 intensifies greenhouse warming, disrupting the carbon cycle.

What if ...

photosynthesis stopped, what would happen on the Earth?

The overuse of fertilisers in agriculture adds excessive nitrogen via nitrates to rivers and lakes, causing widespread growth of algae (algal blooms) that deplete oxygen and kill fish. This process is called **eutrophication** (Fig. 13.17), which threatens water bodies and coastal fisheries. Deforestation also creates multiple effects across air, water, land and living organisms. Clearing forests results in decreased photosynthesis and reduced transpiration, which can lead to decline in the local rainfall. It also alters surface albedo. Without tree roots to hold the soil together, soil erosion could increase. Over time, habitats could be destroyed, leading to a decline in biodiversity as many species lose their natural homes.

Fig. 13.17: Eutrophication (algal bloom)

Threads of Curiosity

Mission LiFE (Lifestyle for Environment), an India-led global initiative introduced at the United Nations Climate Change Conference in 2021, encourages people to adopt mindful, eco-friendly lifestyles. Traditional practices and ancient texts in India have long recognised that the Earth functions as an interconnected system. The Earth works through the flow of energy and the cycling of matter across spheres. Unsustainable consumption disturbs this balance. By promoting simple habits, such as saving energy and conserving resources, Mission LiFE highlights how the actions of individuals and communities can help build a sustainable future.

Vehicular emissions react with sunlight to form ground level smog. This also leads to the formation of ground level ozone, which is harmful for health (remember that ozone in the stratosphere blocks UV radiation and is protective of life). These pollutants make city air unhealthy.

While human impact affects all Earth's spheres, a combination of local actions and global cooperation can help restore the Earth's natural systems. For example, the Montreal Protocol has started the process of recovery of the ozone layer through global cooperation. However, the Kyoto Protocol and the Paris Agreement in which countries were supposed to reduce their CO_2 emissions have been less successful.

Conserving energy and energy resources, switching to renewable energy resources (like solar and wind), planting trees, saving water and practising sustainable farming can help restore the balance. India has planted billions of trees, expanded energy from solar and renewable sources significantly, and also promoted sustainable farming practices. Individuals can also contribute by saving resources (water, food and energy). This can be done by reducing waste, reusing and recycling materials. Together, all these efforts will help maintain the environmental balance on Earth.

Pause and Ponder

6. Discuss how human activities increase the concentration of greenhouse gases in the atmosphere. What would you do as an individual to reduce the emission of greenhouse gas?

At a Glance

- The electromagnetic radiation received from the Sun is the primary source of energy on the Earth.
- Most weather processes like evaporation, condensation and precipitation occur in the troposphere.
- The shape of the Earth, latitude and tilt of the Earth's axis are primarily responsible for variations in insolation, and hence, for the uneven heating of the Earth's surface.
- Uneven heating of the Earth's surface is responsible for the generation of winds and ocean currents.
- Matter and energy are continuously cycled between the living (biotic) and the non-living (abiotic) systems.
- Atmospheric oxygen is used in combustion, respiration and oxide formation, and is restored mainly through photosynthesis.
- On the Earth, water, carbon, nitrogen and oxygen continuously cycle between the atmosphere, oceans, land and living organisms.
- Biogeochemical cycles make nutrients available to living organisms, sustain life, regulate climate and balance ecosystems.

Revise, Reflect, Refine

1. Choose the most appropriate option to describe the role of biogeochemical cycles in an ecosystem.
   (i) To provide food directly to all organisms.
   (ii) To recycle essential nutrients between biotic and abiotic components.
   (iii) To create new elements for use by living things.
   (iv) To remove pollutants and toxins from the organism.
2. Which of the following is primarily responsible for warming of the Earth?
   (i) Solar radiation is immediately absorbed by carbon dioxide, which then releases it as heat.
   (ii) The atmosphere's tiny particles absorb incoming solar radiation, which directly heats the Earth.
   (iii) The Earth's surface absorbs solar radiation, which is then re-radiated and trapped by greenhouse gases.
   (iv) The Earth's environment is heated only by the solar radiation reflected by the clouds.
3. Explain how climate change affects the water cycle. Illustrate with examples.
4. Describe how albedo affects the Earth's surface temperature and its climate.
5. How are mountain and valley breezes formed? Suppose there are two mountains, one covered with grass and another covered with barren rocks; would the temperature of the two mountain breezes be different? If so, how?
6. You have witnessed weather phenomena, such as winds, storms, rainfall, etc. Which atmospheric layer is mainly responsible for such phenomena and what is the primary reason for its occurrence?
7. Explain the processes involved in the nitrogen cycle. How would life on Earth be affected if nitrogen were not cycled?
8. What are the impacts of deforestation on the Earth's oxygen and carbon cycles? What are the other consequences of deforestation?
9. Explain with suitable diagram the path that carbon takes to go back to the atmosphere. You may start from plants using CO_2 from the atmosphere.
10. Why is an excess of CO_2 in the atmosphere considered undesirable even though it is required by plants?
11. How is heat lost from the surface of the Earth? What is its significance?
12. If the Earth were a flat disc instead of a sphere, how would the patterns of solar radiation and temperature be different?

13. Suppose there is a rise in atmospheric temperature on Earth. How would this affect the cryosphere, hydrosphere and biosphere?
14. Explain how the Earth's atmosphere helps in maintaining a suitable temperature for life to survive on the Earth.
15. Describe the interrelationship between different spheres of the Earth. Illustrate with example how these spheres function in a delicate balance.

The Journey Beyond

- Consider two hypothetical Earth-sized planets that have an atmosphere. Assume that one planet is entirely covered by oceans and the other is entirely by land. Knowing that the Sun heats the equator more than the poles, how would the wind patterns on these planets compare with the wind systems we observe on Earth, with its combination of land and sea?
- Choose any one meal you ate recently (it could be anything, for example, roti and dal, rice and sambar, idli and chutney, and so on). For each main item in the meal, find out and explain: (i) how the carbon in it originally came from carbon dioxide in the air through photosynthesis, and (ii) how the nitrogen in it likely came from the atmosphere into the soil (for example, by bacteria or through the Haber-Bosch process and fertilisers) and then into the plant. Further, list other human activities involved in producing or cooking this meal that add extra carbon dioxide or nitrogen to the environment.
- Using data from the India Meteorological Department (IMD, https://mausam.imd.gov.in/) or newspaper records, find the average monsoon rainfall (June–September, or the local season) for your city or district for 5 years during two decades, such as the 1980s and 2020s. Note any trend you may find (increasing or decreasing, or the total number of days) with heavy rain (>50 mm). How can this be connected to the warmer Arabian Sea temperatures or changes in land use (forests to farms to cities) as discussed in the chapter?

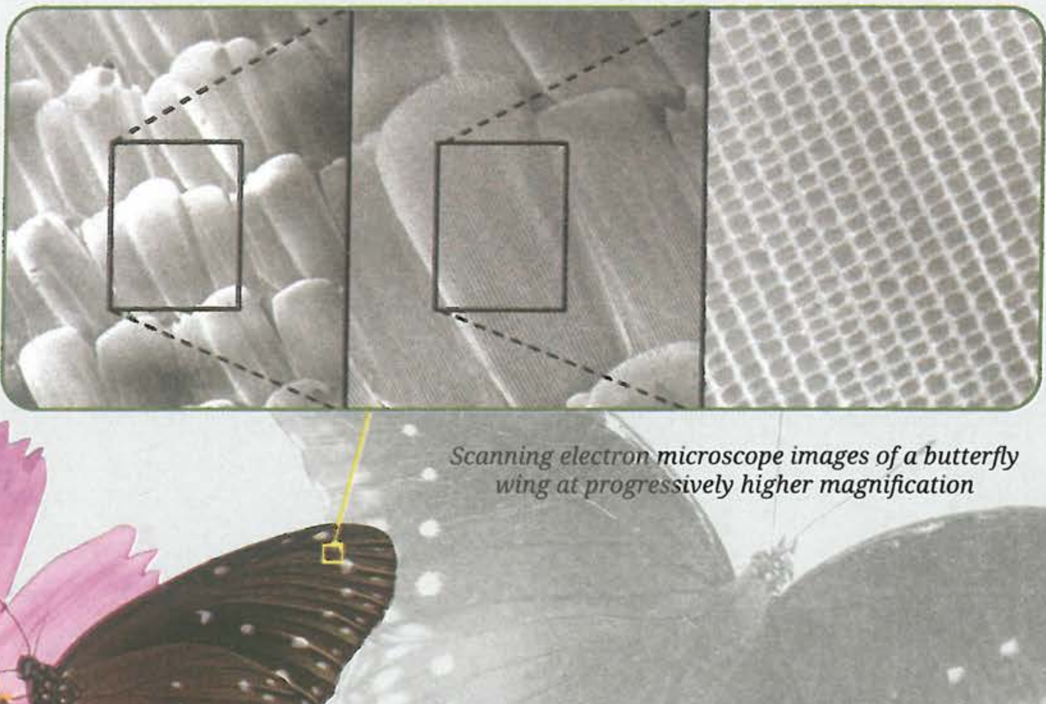
The Quest Continues ...

New tools are allowing scientists to observe the planet in real time and uncover hidden connections between climate, ecosystems, and human activity. What new discoveries will these tools reveal about the changing Earth, and how will they improve our understanding of global warming and climate change?

Ready for New Horizons?

As you reach the end of this book, look back on your journey in science, from first being curious about the world around you to exploring it with deeper understanding and clearer ideas. You have travelled across the hidden world inside cells and atoms, learnt about the forces that shape motion, work and mechanical energy, the science of sound, and the systems that make our planet a living world. Together, these ideas show that science is not a collection of facts, but a connected way of understanding nature. More importantly, we hope you have learnt to think like a scientist—asking questions, looking for evidence and trying to understand patterns in nature. These ways of thinking also help us understand the technology around us, make informed choices, and see connections between the human life and the natural world.

In Grade 10, your journey of curiosity and exploration will become even more exciting. You will explore how life sustains itself, how traits are passed from one generation to the next, how chemical reactions transform matter, and how electricity, magnetism and light power our modern world. You will encounter ideas on scales from the large to the small, just as the electron microscope images given below reveal the beautiful structure of a butterfly wing at progressively higher magnifications. The habit of wondering *why*, testing *how*, and exploring *what if* are keys to solving the real-world challenges society is facing today. Science is an ongoing human adventure and you are now prepared not just to learn it but to question it, and to participate in it. The next discoveries may come from someone who is learning science today, someone like you!



Scanning electron microscope images of a butterfly wing at progressively higher magnification

Answer Key

Chapter 2

Revise, Reflect, Refine

2. (iii) 4. (i) 7. (ii) 11. (iii)

16. (i) Osmosis
    (ii) Concentration of salt or sugar is higher than the cell sap of bacterial or fungal cell, and therefore, water inside the cell comes out due to osmosis.

Chapter 3

Revise, Reflect, Refine

1. (iii) 2. (iii) 3. (ii) 5. (iii)
6. A (iii) B (i) C (iv) D (iii)

Chapter 4

Pause and Ponder

4. 80 km h^{-1}; 0 km h^{-1}

Revise, Reflect, Refine

1. 1000 m; 0 m
2. (i) 18 m (ii) 6 m in upward direction
3. Yes, Yes, different
4. 4 m s^{-2} in the direction of velocity, 72 m
5. -4 m s^{-2} in the direction opposite to the velocity; 7 s
6. No
7. (i); (ii)
8. 450 m
9. 310 m
10. 25 m; Yes
12. 320 m; $\frac{1}{60}$ m s^{-2}
14. 774 m
15. 12.5 m; 15 m
16. (i) 66 cm (ii) 14 cm (iii) $\frac{11}{900}$ cm s^{-1} (iv) $\frac{7}{2700}$ cm s^{-1}

Chapter 5

Pause and Ponder

1. 12 g
2. 20 % *v/v*

Revise, Reflect, Refine

1. (iv)
2. (iii)
4. (i) % *m/m*; Sugar = 15%; All-purpose flour = 84%; Sodium hydrogencarbonate = 1%
   (ii) Copper = 84 g; Zinc = 36 g
6. (iii)
14. (i) Student A = 20%; Student B = 16.67%; Student C = 27.27%
    (ii) Student C

Chapter 6

Pause and Ponder

2. No; S
3. No
4. (i); (ii)
6. 0 N

Revise, Reflect, Refine

1. *F* in the direction opposite to the applied force.
2. (i) same (ii) increase (iii) decrease
3. (i)
4. 18,000 N in the forward direction
5. (iv)
6. (iii)
9. (iv)
11. 25 N
12. 500 N in the direction opposite to the motion
13. 0.015 s
14. 10 m
15. $\frac{a_1 a_2}{a_1 + a_2}$

Chapter 7

Pause and Ponder

1. No
2. Negative
4. 2:1
5. No
6. No; yes

Revise, Reflect, Refine

1. (i) F (ii) T (iii) T (iv) F (v) T
2. (i) Force; Displacement (ii) 1 (iii) $\frac{1}{2}mv^2$ (iv) *mgh* (v) rate
3. (iii); (iv)
5. (i) 36250 J (ii) 36250 J
   (iii) does not depend upon the path
6. Energy twice of initial energy; power same as initial power
8. 4:5
10. (i) Negative and positive (ii) -12 J
11. 6 m s^{-1}; $\sqrt{66}$ m s^{-1}; No
12. 48 m
13. (i) with constant speed
    (ii) 612500 J (iii) -612500 J
    (iv) potential energy
14. $2\sqrt{10}$ m s^{-1}; 0 m s^{-1}; The ball cannot reach position R
15. (i) $10\sqrt{2}$ m s^{-1} in the direction of motion
    (ii) 0.05 m

Chapter 8

Pause and Ponder

7. (ii)
10. Electrons 26; Protons 26; Neutrons 30
11. Neutrons 21
12. Mass number 35
13. Neutrons 12
14. (i) 4 (ii) 7 (iii) 4
15. 2, 8, 2; 2, 8, 6; 2, 8, 8
16. Sodium; 12
18. 80.006 u

Revise, Reflect, Refine

1. (ii), (iii) are correct
2. (iii) is correct
3. (i) Isotopes (ii) Isobars
7. (ii)
8. (i) Protons 12 (ii) Neutrons 12
   (iii) Electrons 12;
   Electronic configuration 2, 8, 2
9. (a) (i) Lithium; (ii) Li; (iii) 3; (iv) 1; (v) 1; (vi) 3; (vii) 3
   (b) (i) Nitrogen; (ii) N; (iii) 7; (iv) 5; (v) 3; (vi) 7; (vii) 7
   (c) (i) Aluminium; (ii) Al; (iii) 13; (iv) 3; (v) 3; (vi) 13; (vii) 13
   (d) (i) Fluorine; (ii) F; (iii) 9; (iv) 7; (v) 1; (vi) 9; (vii) 9
11. Neutrons 39

12. (i) Neutrons 118 (ii) Electrons 79

13.

Atomic number	Mass number	Number of neutrons	Number of protons	Number of electrons	Name of the 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

14. (i) Electrons 17; Protons 17
(ii) Atomic number 17
(iii) Chlorine
(iv) Electronic configuration 2, 8, 7
(v) Valence electrons 7
(vi) Mass number 37
(vii) Isotopes

Chapter 9

Pause and Ponder

2. 180 g
3. 30 g
4. 12 g
7. (iii)
12. Anion (O^{2-})
13. Cl^-; one; two
16. (i) Carbon dioxide (ii) Nitrogen dioxide
(iii) Sulfur hexafluoride
(iv) Phosphorous trichloride
17. (i) $NaHCO_3$ (ii) SO_2
(iii) $FeCl_3$ (iv) Cu_2O
18. (i) $Fe(OH)_3$ (ii) K_2CO_3
20. (i) MO (ii) Ionic
(iii) Conducts electricity in aqueous solution
21. 63 u
22. 16 u
23. 74.5 u
24. 58 u

Revise, Reflect, Refine

1. (i) tends to give 1 electron
(ii) Cation (A^+)
(iii) tends to take 2 electrons
(iv) Anion (B^{2-})
(v) Ionic
(vi) A_2B
3. (iii)
4. (iv)
5. (i) $Al(NO_3)_3$ (ii) CaO
(iii) Fe_2O_3
6. (i) $CaBr_2$ (ii) $Al_2(CO_3)_3$
(iii) K_2SO_4 (iv) NH_4Cl
7. (ii)
8. (i) 80 u (ii) 98 u
(iii) 84 u
9. (i) Mg_3N_2 (ii) Li_3N
(iii) Na_2S (iv) Al_2O_3
10.

	NO_3^-	SO_4^{2-}	PO_4^{3-}
NH_4^+	NH_4NO_3	$(NH_4)_2SO_4$	$(NH_4)_3PO_4$
Li^+	$LiNO_3$	Li_2SO_4	Li_3PO_4
Al^{3+}	$Al(NO_3)_3$	$Al_2(SO_4)_3$	$AlPO_4$
Cu^{2+}	$Cu(NO_3)_2$	$CuSO_4$	$Cu_3(PO_4)_2$

12. (i) $Z = 11$; $A = 23$
(ii) Cation
(iii) Electronic configuration 2, 8
(iv) Sodium cation (Na^+)
13. (i) Element B
(ii) Covalent
(iii) AB_3
14. (iii)
15. Electrons 13, Neutrons 14; Electrons 36, Neutrons 45; Electrons 78, Neutrons 121

Chapter 10

Pause and Ponder

3. (ii)
4. (iii)
5. (ii)
8. 1200 oscillations
9. 1.5 cm
10. (i) 75:17 (ii) 10:3
11. 0.932 s; Yes
12. 34.3 m
13. 3000 m

Revise, Reflect, Refine

1. (ii)
2. (iii)
3. 5 Hz
5. (i) (a) (ii) (a)
6. A - Green curve; B - Red curve; C - Blue curve
9. 0.01 s
10. 3812.5 m
11. 0.007 s
12. $\frac{65}{331}$ s
13. 0.04 m; 8500 Hz
14. 0.025 m, 0.05 m; 13800 Hz, 6900 Hz
15. 2:9

Chapter 11

Pause and Ponder

5. Internal Fertilisation
6. Adolescence
7. 2nd April
8. 46 Chromosomes

Revise, Reflect, Refine

1. (iii)
2. Correct sequence is (iii), (i), (ii), (iv)
3. (iv)
11. Tomato—self pollination; wheat—self pollination; papaya—cross pollination

Chapter 12

Revise, Reflect, Refine

1. (ii) 2. (iii)
15. (i) Q (ii) P, characterised by no true nucleus
(iii) both can be classified based on level of organisation, the organism Q is multicellular and organism R is unicellular
(v) There is no place for acellular entities

Chapter 13

Revise, Reflect, Refine

1. (ii)
2. (iii)