Science

Class Nine

Investigative Study

NATIONAL CURRICULUM AND TEXTBOOK BOARD, BANGLADESH

অপরাজেয় বাংলা

সাবাস বাংলাদেশ

বিজয় '৭১

মুক্তিযুদ্ধ বিষয়ক কয়েকটি ভাস্কর্য

ক. অপরাজেয় বাংলা: অপরাজেয় বাংলা ভাস্কর্যটি বাংলাদেশের স্বাধীনতা যুদ্ধের স্মরণে নির্মিত যাতে তিনজন মুক্তিযোদ্ধাকে চিত্রায়িত করা হয়েছে। শিল্পী সৈয়দ আব্দুল্লাহ খালিদ ১৯৭৯ সালে এটির নির্মাণ কাজ শেষ করেন। ঢাকা বিশ্ববিদ্যালয়ে কলা ভবনের সামনে এটি অবস্থিত ।

খ. সাবাস বাংলাদেশ: সাবাস বাংলাদেশ ভাস্কর্যটি বাংলাদেশের অন্যতম বৃহৎ ভাস্কর্য যা ১৯৭১ সালে মুক্তিযুদ্ধে অংশগ্রহণকারী তরুণ মুক্তিযোদ্ধাদের প্রতীকীরূপ। ১৯৯১ সালে শিল্পী নিতুন কুণ্ডু এটির নির্মাণ কাজ শেষ করেন। ভাস্কর্যটি রাজশাহী বিশ্ববিদ্যালয় চত্বরে অবস্থিত।

গ. বিজয় '৭১: মহান মুক্তিযুদ্ধে বাংলাদেশের সর্বস্তরের মানুষের স্বতঃস্ফূর্ত অংশগ্রহণের মূর্তপ্রতীক এই ভাস্কর্যটি। ময়মনসিংহের বাংলাদেশ কৃষি বিশ্ববিদ্যালয় ক্যাম্পাসে এটি অবস্থিত। ভাস্কর্যটির শিল্পী শ্যামল চৌধুরী, নির্মাণ কাজ শেষ হয়েছে ২০০০ সালে।

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Science
Investigative Study

Class Nine

(Experimental Version)

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PREFACE

In this ever-changing world, the concept of life and livelihood is changing every moment. This process of change has been accelerated due to the advancement of technology. There is no alternative to adapting to this fast changing world as technology is changing rapidly ever than before. In the era of fourth industrial revolution, the advancement of artificial intelligence has brought about drastic changes in our employment and lifestyles that will make the relationship among people more and more intimate. Various employment opportunities will be created in near future which we cannot even predict at this moment. We need to take preparation right now so that we can adapt ourselves to that coming future.

Although a huge economic development has taken place throughout the world, problems like climate change, air pollution, migrations and ethnic violence have become much more intense nowadays. The breakouts of pandemics like COVID 19 have crippled the normal lifestyle and economic growth of the world. Thus, different challenges as well as opportunities, have been added to our daily life.

Standing amid the array of challenges and potentials, sustainable and effective solutions are required to transform our large population into a resource. It entails global citizens with knowledge, skill, values, vision, positive attitude, sensitivity, adaptability, humanism and patriotism. Amidst all these, Bangladesh has graduated into a developing nation from the underdeveloped periphery and is continuously trying to achieve the desired goals in order to become a developed country by 2041. Education is one of the most crucial instruments to attain the goals. Hence, there is no alternative to the transformation of our education system. This transformation calls for developing an effective and updated curriculum.

Developing and updating the curriculum is a routine and important activity of National Curriculum and Textbook Board. The curriculum was last revised in 2012. Since then, more than a decade has elapsed. Therefore, there was a need for curriculum revision and development. With this view, various research and technical studies were conducted under NCTB from 2017 to 2019 to analyze the current state of education and identify the learning needs. Based on the researches and technical studies, a competency-based and seamless curriculum from K−12 has been developed to create a competent generation capable of surviving in the new world situation.

Under the framework of this competency based curriculum, the textbooks have been prepared for all streams (General, Madrasah and Vocational) of learners for Class Nine. The authentic experience-driven contents of this textbook were developed with a view to making learning comprehensible and enjoyable. This will connect the textbooks with various life related phenomenon and events that are constantly taking place around us. It is expected that, through this, learning will be much more insightful and lifelong.

In developing the textbooks, due importance has been given to all − irrespective of gender, ethnicity, religion and caste while the needs of the disadvantaged and special children are taken into special considerations.

I would like to thank all who have put their best efforts in writing, editing, revising, illustrating and publishing the textbook.

If any errors or inconsistencies in this experimental version are found or if there is any suggestions for further improvement of this textbook, you are requested to let us know.

Professor Md. Farhadul Islam
Chairman
National Curriculum and Textbook Board, Bangladesh

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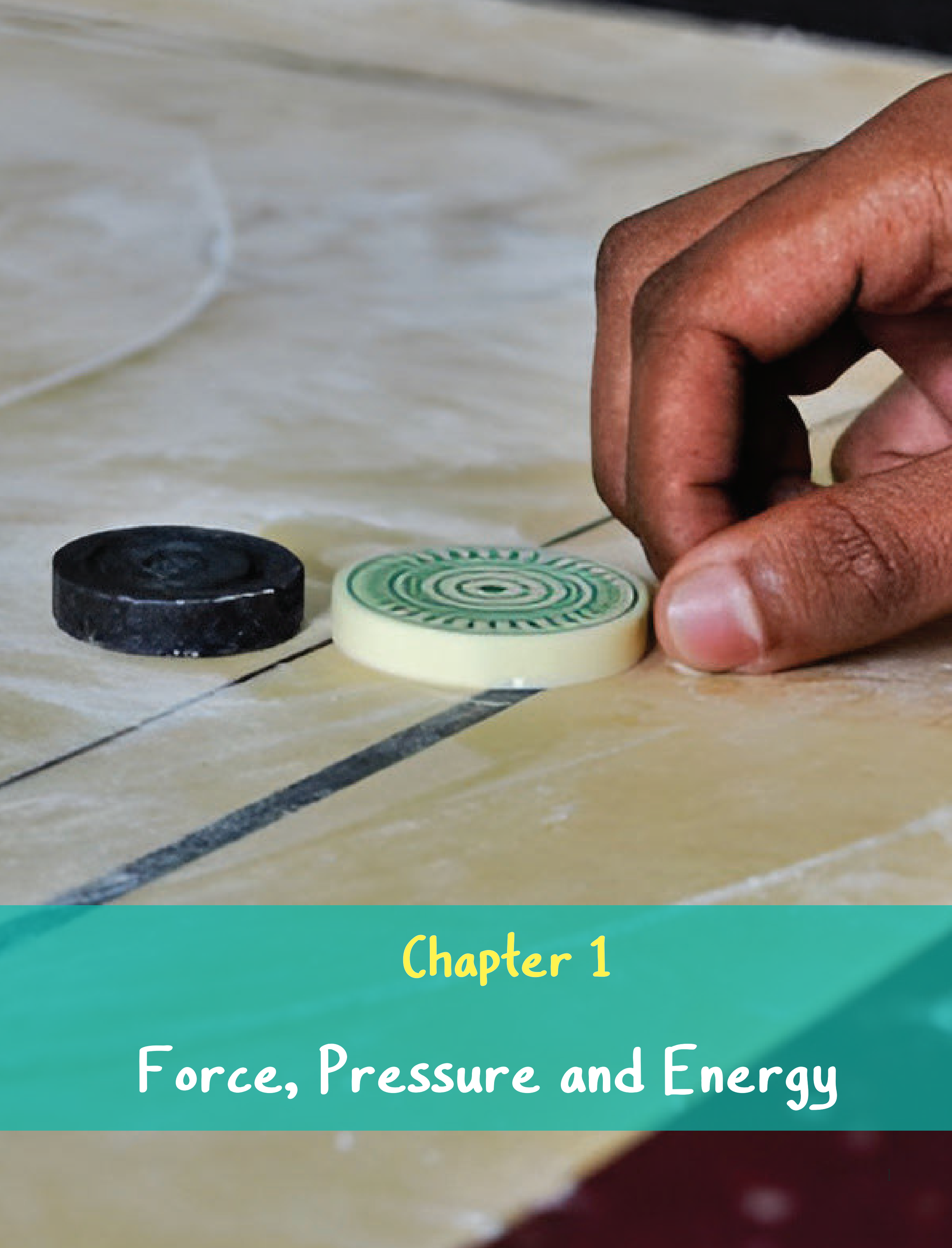
A few words for the students-

Students, how are you all? Welcome to the Science subject of Class Nine.

You can see, there is going to be a big change in the way you have been studying for so long! Your books on all subjects are also a little different this time. You must have got two books on Science! Along with this 'Investigative Study' book you are given another 'Exercise Book'. If you have a look, you will realize that there is a big difference between this book and the Exercise book. Honestly speaking, the way you used to try to learn science by reading different chapters of textbooks, now this way of learning is completely changing. Throughout the year, you will go through several new experiences, solve some new problems. These new experiences and problem solving steps are detailed in your work book. In solving these problems, you will need to know different aspects of science at different stages. This 'Investigative Study' book will help you in this regard. At school or at home, wherever you are, you can use this book to solve problems yourself if needed!

This book covers the topics of Science that you will need to know in Class Nine. The topics are organized in Fourteen chapters. Many of these things will be useful to you at different times in the experiences that you will go through throughout the year.

So let us start, what do you say?



Chapter 1

Force, Pressure and Energy

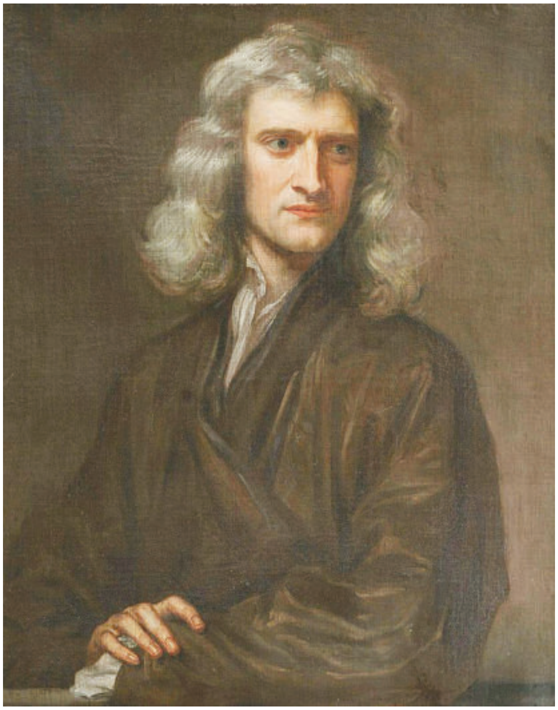
Chapter 1

Force, Pressure and Energy

This chapter discusses the following topics:

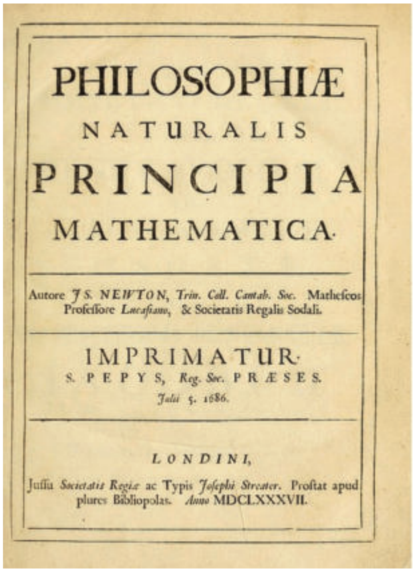
☑ Newton’s First Law
☑ Newton’s Second Law
☑ Force
☑ Four Kinds of Force
☑ Newton’s Third Law
☑ Gravitational Force and the law of Gravity
☑ Pressure, Archimedes' principle and Buoyancy
☑ Energy: Kinetic and Potential

In the previous grade, you learned a bit about motion-related terms and also came to know how to express, with some simple mathematical equations, the changes in these quantities over time. That is, you learned about the definitions of terms such as displacement, velocity, and acceleration, and the equations that relate them. But the science behind where that motion comes from is only hinted at, but not explained. In this chapter, for the first time, you will be told where that motion comes from and how it relates to force. You will see how Newton's three groundbreaking laws can be used to analyze the motion of everything from planets and satellites to rockets and cars, to even cricket balls.



Philosophiae Naturalis Principia Mathematica

Isaac Newton was a British physicist who made significant contributions to many subjects such as motion, gravity, and light almost three centuries ago. Newton was also an extremely expert mathematician. He was considered the inventor of calculus along with German mathematician Leibniz. Newton was both a theoretical and practical scientist. His ideas about motion and gravitation were purely theoretical, but he proved much by direct experiment in many matters relating to light. As scientists' works are now published through scientific journals, this was not the case three centuries ago. Then some people wrote books and published their work. Newton wrote a book called 'Philosophiæ Naturalis Principia Mathematica'. This masterpiece written in Latin is known as “Mathematica”.



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *JS. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheſeos
Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtat apud
plures Bibliopolas. *Anno* MDCLXXXVII.

1.1 Newton’s First Law

Newton’s first law of motion is often referred to as the law of inertia. This law explains how an object’s motion remains unchanged if no force is applied to it. Before understanding this law, it is necessary to understand the concepts of Static Inertia and Dynamic Inertia.

1.1.1 Static Inertia and Dynamic Inertia

If you are standing in a bus or train, and suddenly the bus or train starts moving, you will notice that you want to fall backwards. As your lower body, touching the floor of the bus or train, begins to move forward, but your upper body wants to remain in its previous position, your upper body leans back, and you tend to fall. If you put a coin on a piece of paper or cardboard on top of a glass and pull the paper away, you will see that the coin falls inside the glass instead of with the paper (Figure 1.1). That is, the coin tries to stay in its previous position even as the paper moves. The fact that a stationary object wants to remain stationary is called Static Inertia.

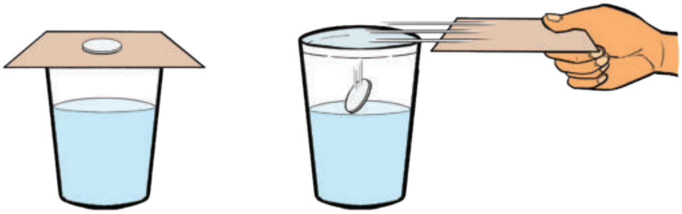


Figure 1.1: If the cardboard is moved away, the coin will fall into the glass because of static inertia.

You must have noticed that when a moving car is stopped suddenly, our body jerks and leans forward. Braking causes the lower body to stop with the car but our upper body is still in motion, causing it to lean forward. Have you ever seen someone getting off a moving bus or train? Those who are experienced in this matter run a short distance with their feet on the ground but do not stop. They know that if they land on the ground their feet will stop but the rest of the body will still remain in motion, so if the lower part of the body is not released at the same speed, it will fall down. Figure 1.2). The fact that an object in motion wants to maintain its previous speed is called 'Dynamic Inertia'.

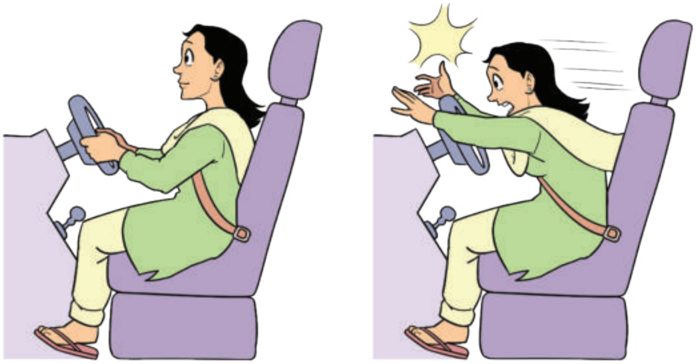


Figure 1.2: When a moving car is stopped suddenly, our body jerks and leans forward because of dynamic inertia.

Food for thought:

- Dust can be removed by beating a kantha or a blanket with a stick, why?
- Spin bowlers bowl from almost a standing position, but pace bowlers run from a distance. Why?

1.1.2 Newton's First Law: Definition and Explanation

Static inertia and Dynamic inertia together are called inertia. That is, the tendency of stationary objects to remain stationary and moving objects to remain in motion is inertia. Newton stated this inertia in his first law of motion.

» Newton's First Law: An object at rest remains at rest, and an object in motion remains in motion at constant speed and in a straight line unless acted on by an external force.

We don't have a problem with the first part of this law. We see it all the time in everyday life that if a stationary object is not pushed, it stays still, not moving on its own. But we may have a little trouble understanding the latter part from everyday experience, because we do not see any object in motion going on forever. But the answer to this problem is given at the beginning of Newton's first law, which speaks of 'external force'. Whenever you set an object in motion, forces such as friction or air resistance act in the opposite direction to slow down the motion. Since there is no air in space, there is no air friction, so if an object could be pushed out there, it would continue at the same speed forever.

Food for thought:

The adjacent figure shows a heavy object hanging by a string, and another string hanging below the object. A jerky pull on the lower thread will tear the A thread and a slow pull will tear the B thread (Figure 1.3). Why?

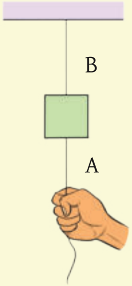


Figure 1.3: A jerky pull will tear the A thread and a slow pull will tear the B thread.

1.2 Newton's Second Law

Newton's first law states how an object moves when no force is applied to it. You will see that Newton's second law explains how an object moves when force is applied to it. In the previous grade you learned that force must be applied to change velocity, Newton's first law reaffirmed that fact. The first formula, however, does not say anything about the scientific definition of force or how to measure force. The method of measuring force is derived from Newton's second law.

Before learning Newton's second law, you need to be familiar with a new term, momentum.

1.2.1 Concept of Momentum

If someone comes towards you on a bicycle with a speed of 1 ms^{-1}, you can stop him by putting your hand on the handle of his bicycle. But if someone drives a car with a speed of 1 ms^{-1}, you cannot stop the car by holding it with your hand, even though both the bike and the car were moving at the same speed. The difference between the two is actually the mass. A bicycle is a low-mass or light object, a car is not at all, it is an object of high mass. That is, there is a matter of mass being less or more besides the velocity while changing the speed by applying force.

If someone throws a small stone at you with a velocity of 1 ms^{-1}, you can easily catch the stone. Now if he throws the same stone at you with a slingshot at 100 ms-1, you will not dare to catch it. Although the two stones are the same, i.e. they have the same mass, in both cases, the stone is not moving at the same speed. It is understood that the difference in this case is the velocity. That is, in addition to mass, there is also a matter of increasing or decreasing velocity while applying force to change motion.

From these two examples, you can understand that the change in motion of an object by applying a force depends on both the mass of the object and the velocity of the object. That is why a new quantity is needed to combine mass and velocity, called momentum. It is actually the product of mass and velocity. You might think that since there are two quantities, mass, and velocity, there was no need to create a new quantity by multiplying them. Your idea is true in our daily familiar life, but you will be surprised to know that when the speed of an object approaches the speed of light, momentum is no longer just the product of mass and velocity. Not only that, light particles (photons) have zero mass but their momentum is not zero! You will know it in more detail in higher grades. For now, we will refer to momentum as the product of mass and velocity.

Momentum is expressed by the English letter p. If mass and velocity are m and v respectively then p = mv and the unit of momentum is obtained by multiplying the unit of mass (kg) and unit of velocity (ms^{-1}). That is, kg ms^{-1} is the unit of momentum.

As velocity has direction, momentum also has direction; the direction of an object's velocity is its direction of momentum.

Example: In the previous paragraph, values for the velocity of the bicycle, car, and stone were given, but not for the mass. If the mass of the bicycle is 75 kg, the mass of the car is 2000 kg and the mass of the stone is 5 g, what is the momentum in all four cases?

Solution: The momentum of the bicycle is $p_1 = m_1v_1 = 75 \times 1 = 75$ kg ms^{-1}

Momentum of car $p_2 = m_2v_2 = 2000 \times 1 = 2000$ kg ms^{-1}

Momentum of stone thrown by hand is $p_3 = m_3v_3 = 0.005 \times 1 = 0.005$ kg ms^{-1}

The momentum of the slingshot is $p_3 = m_3v_3 = 0.005 \times 100 = 0.5$ kg ms^{-1}

1.2.2 Rate of Change

In order to understand Newton's second law, we need to understand one more thing, that is the rate of change. We are all familiar with the term 'change', if the value of any quantity increases or decreases then we say that the quantity has changed. The amount that has increased or decreased is the amount of change. We use the term rate of change to describe how fast the change is occurring.

Suppose you and your friend have gone out for a bicycle ride, both start from rest and reach a velocity of 10 ms^{-1}, it takes you 2 seconds and your friend 2.5 seconds. We can tell without calculating that your rate of change of velocity is greater because you reached the same velocity in less time. If we calculate, then,

Rate of change of your velocity = $(10\ ms^{-1} - 0)/2s = 5\ ms^{-2}$

Rate of change of velocity of your friend = $(10\ ms^{-1} - 0)/2.5s = 4\ ms^{-2}$

By calculating we get the same answer. Suppose again you and your friend have gone for a bicycle ride, this time both start from rest and cycle for 5s and find that your velocity is 20 ms^{-1} and your friend's velocity is 25 ms^{-1}. This time also we can say without calculation that this time the rate of change of velocity of your friend is higher because the value of his velocity is higher by cycling for the same amount of time. If we calculate, Rate of change of your velocity = (20 ms^{-1} – 0)/5s = 4 ms^{-2}

Rate of change of velocity of your friend = (25 ms^{-1} – 0)/5s = 5 ms^{-2}

This time too we got the same answer. So you must have understood that the rate of change of a quantity with time is called the rate of change. In the previous grade, we learned about velocity and acceleration. Now we can say, velocity was the rate of change of displacement with time, and acceleration was the rate of change of velocity with time.

Example: If each object in the example from the previous paragraph is stopped for 1 minute, what is the rate of change in momentum in each case?

Solution: Rate of change in momentum = (initial momentum – final momentum)/ elapsed time

Here, the objects are coming to rest, i.e. the final velocity is zero, hence the final momentum is also zero

Rate of change in momentum of bicycle = (75 - 0)/60 = 1.25 kg ms^{-2}

Rate of change in momentum of car = (2000 - 0)/60 = 33.33 kg ms^{-2}

Rate of change in momentum for stone thrown by hand = (0.005 - 0)/60 = 8.33 x 10^{-5} kg ms^{-2}

Rate of change in momentum for a stone thrown in a sling = (0.5 - 0)/60 = 8.33 x 10^{-3} kg ms^{-2}

1.2.3 Newton's Second Law: Definition and Explanation

Newton's second law is one of the most important laws in Physics. With this simple formula, almost everything related to motion in our known world can be done. Everything from children's marble games to rockets into space can be explained with this formula. You already know how small the atom is, and you also know how fast the speed of light is; in these two cases - that is, in the case of very small lengths comparable to the size of atoms or very large speeds comparable to the speed of light, Newton's law does not apply. The first case requires quantum theory, and the second case requires relativity theory. You will learn about both in the next chapter. Since we do not even come close to it in our daily lives, we cannot feel their need separately. Newton's second law applies perfectly to almost everything in the visible world around us. Newton's second law is:

» Newton’s Second Law: The rate of change in momentum of an object is proportional to the force applied to it, and the change in momentum also takes place in the direction the force applied.

Newton's second law states the proportional relationship between force and rate of change in momentum. Consider an object of mass m moving with velocity u, when a force of magnitude F is applied to it from outside for time t, the velocity changes to v. That is, the momentum at the beginning of the application of the force is mu and the momentum at the end of the application of the force is mv, and the change in momentum will be their difference,

That is, change in momentum = mv - mu

Then, rate of change in momentum = (mv - mu)/t

Since there is no change in mass, rate of change in momentum = m(v - u)/t

But we know acceleration a = (v - u)/t

So rate of change in momentum = ma

According to Newton's law, the rate of change in momentum is proportional to the applied force, ie

$$ma \propto F \text{ or } F \propto ma$$

If we want to write this as an equation rather than as a proportional relationship, then a constant of proportionality is needed. That is, we write like this,

$$F = kma$$

where k is the proportionality constant. Since Newton's second law does not say anything about the value of the constant of proportionality, it has to be determined by experiment. That is, by applying a certain amount of force (F) on an object of a certain mass (m), the acceleration (a) has to be seen, and then the value of the proportionality constant (k) will be found out. But here a very surprising thing happened. Nowhere does it say what is meant by a 'certain amount of force' because the method of measuring force had not been fixed until then! So scientists decided to use Newton's second law to measure force! That is, it was fixed that the amount of force which causes 1 unit of acceleration of 1 unit mass is 1 unit of force. That is, if m=1 and a=1 then F=1. Then there is no need to find the value of k separately, because then the value of k becomes 1! Thus Newton's second law takes a very simple form:

$$F = ma$$

The unit of force is named Newton (abbreviated N) in honor of Newton's memory, i.e. the force required to move an object of mass 1 kg with an acceleration of 1 ms^{-2} is exactly 1 N. Since force is the rate of change in momentum, and since momentum has a definite direction, force has a definite direction.

Example: What is the amount of the force exerted on each object in the example from the previous paragraph?

Solution: Since, force = rate of change in momentum

Force applied on the bicycle = 1.25 N

Force applied on the car = 33.33 N

Force applied on stone thrown by hand = 8.33×10^{-5} N

Force applied on the stone thrown by sling = 8.33×10^{-3} N

Example: A car of mass 750 kg moving at 50 ms^{-1} increases its velocity to 70 ms^{-1} in 10 s, what is the force applied by the engine of the car?

Solution: Here, the acceleration of the car is $a = (v - u)/t = (70 - 50)/2 = 10$ ms^{-2}

The mass of the car is $m = 750$ kg

That is, the force applied by the engine is $F = ma = 750 \times 10 = 7500$ N

1.3 Concept of Fundamental Force

As you can imagine there are many types of force in the world! It is a force when a railway engine pulls a train carrying passengers, a force when houses are blown away in a storm, the attraction or repulsion of magnets is a force, a force when cricketers hit a six with the bat in cricket, when a crane does heavy Pulling is also a force —you can't actually count the number of forces! Although there are so many different types of forces around you, the amazing thing about science is that there are actually only four types of force in nature! They are: Gravitational Force, Electromagnetic Force, Weak Nuclear Force, and Strong Nuclear Force. If you analyze the surrounding forces, it will be seen that there are none beyond these four types! These are called fundamental forces. Among them, in our daily life, we only feel the force of gravity and the force of electromagnetism, the other two are in nature but not easily perceived.

Four types of force

Gravitational force is the force by which all objects in this universe attract each other due to their mass. Due to this gravitational force, the stars in the galaxy rotate or the earth rotates around the sun, and the moon rotates around the earth! When the earth's gravitational force acts on us, we call it gravity.

Many of us have done it at one time or another, combing our hair and attracting a piece of paper with it, or using a magnet to attract and repel another magnet. Although electric and magnetic forces seem to be different forces, they are actually two same forces. Its name is electromagnetic force.

The third fundamental force is called the weak nuclear force. The neutrons that accompany the protons in the nucleus of an atom are stable inside the nucleus, but when free, they split into protons, electrons, and neutrons within ten minutes. This process is known as beta (β) radiation and is caused by the weak nuclear force.

The last fundamental force is called the strong nuclear force. The protons and neutrons in the center of the atom are held together by this very strong force. Due to this force, it is possible to generate electricity in nuclear power plants by releasing the huge energy stored inside the nucleus.

Variation of Values in Basic Forces

If we compare these four basic forces, it can be seen that their values vary greatly. For example, the first fundamental force of physics is the gravitational force, which we experience all the time in our daily lives. Any object that has mass attracts other objects with a gravitational force. It is very surprising that this ball is the weakest compared to the rest of the balls.

Electromagnetic force can both attract and repel, while others can only attract and not repel. This force is 10^{36} times stronger than the force of gravity. It can be easily verified that the statement is true. A bit of paper can be easily pulled out by combing the hair with a comb. Then the earth tries to pull that piece of paper with all its gravitational force, yet a little bit of electricity from the comb defeats the entire gravitational force of the huge earth.

The weak nuclear force is called weak because it is about a hundred billion times (10^{-11}) weaker than the electromagnetic force, yet much stronger than the gravitational force.

The strongest force in the universe is the strong nuclear force, which is about a hundred times stronger than the electromagnetic force. It is because of this force that protons and neutrons can stay very close to the nucleus of an atom against the electromagnetic repulsion force.

Variation of Range in Basic Forces

After learning about the difference in value of the four fundamental forces in the previous paragraph, you must be wondering, since the strong nuclear force is so strong, how come the other weak forces are in effect? This question is very logical, but so far the proportion of the basic forces has been discussed, but not the distance at which the forces are effective. The extent to which a force can spread its influence is called the range of that force. Gravitational and electromagnetic forces can act at any distance, so their range is infinite. At great distances, the effect of these forces becomes very weak, but never zero. That is why, the galaxies from the solar system to the giants survive under the influence of the gravitational force despite it being very weak.

On the other hand, nuclear forces act over very short distances. For example, the strong nuclear force acts at a distance of 10^{-15} m and the weak nuclear force acts at a thousand times less distance of 10^{-18} m. If the range of the nuclear force was greater than the force of attraction of gravity or the electromagnetic force, nothing from the galaxy to the atom could have been formed, which means that the universe would not have existed.

Food for thought:

- Gravity and electromagnetic forces can act at any distance, but why do we see the gravitational force being most effective at cosmic distances, even though the electromagnetic force is 10^{36} times stronger than the gravitational force?

1.4 Newton's Third Law

From Newton's first law, we know what happens when no force is applied to an object. And we know what happens when force is applied to the object from Newton's second law. When one object exerts a force on another object, we will know the interaction between the two objects from Newton's third law. Newton's third law explains our walking or running. Newton's third law is also used in jet engines or rocket engines going to space (Figure 1.4).

Figure 1.4: Space Rocket

When discussing Newton's first and second laws, we talked about force, but not who or what is exerting the force. In real life, force is always exerted by some object on another object. Newton's third law tells us what reaction occurs between two objects when one exerts a force on another.

Newton's third law is written in many ways but for ease of understanding, can be simply and clearly written as:

» **Newton's Third Law:** When one object exerts a force on another object, that object also exerts an equal force on the first object in the opposite direction.

The force applied is often called action and the force returned in the opposite direction is called reaction. You see, the force never stands alone, it always comes in pairs—meaning that if there is an action, there must be a reaction. It is never possible to get only action or only reaction separately.

One thing that is often confused when learning Newton's third law is that if two forces are equal and opposite to each other, why doesn't one cancel the other? Therefore, before learning the third law, it is very important to understand that if there are two separate objects A and B, and when A exerts a force on B, B exerts a force on A. That is, the two forces are equal and opposite but they act on two different objects, never on the same object. If the two forces were applied to the same object, they could only cancel each other out, but there is no chance of that here. One of the forces applied to these two separate objects is action, the other is reaction (Figure 1.5). A few examples will make the matter more clear.

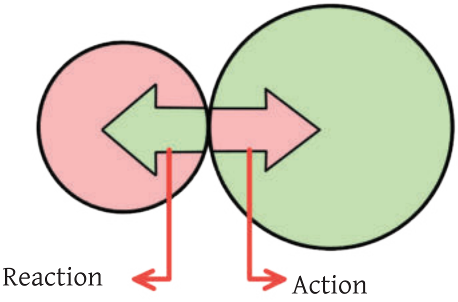


Figure 1.5: Action and Reaction

Figure 1.6: The table pushes back if you push it

If you push a heavy table, you will feel the table pushes you back (Figure 1.6). You can see there are two objects, one is yourself, and the other is the table. You exert a force (or action) on the table, so the table exerts a force (or reaction) on you. This is action and reaction. If you had to throw a punch in a vacuum, you probably wouldn't mind, because of how little or no force can be exerted on the air. But if you were asked to punch a hard concrete wall, you would probably not agree, because the concrete would cause you enough pain.

The easiest way to understand Newton's third law is to understand how one walks. From a stationary position one can walk, which means there is an acceleration while walking, which means that force is applied to walk. But we all know that when someone walks, no one exerts a force on them, so where does the force come from? Without the concept of action and reaction, we could never explain walking. Because of this reaction, one can walk! That's why you can't walk in very slippery places. If the foot on the floor is not able to exert a backward force on the slippery surface, the foot slips. As no force can be applied, there is no opposite force.

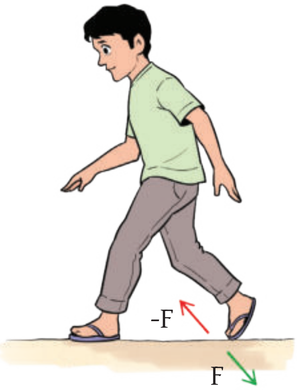


Figure 1.7: Action and reaction are at work during walking

The same thing happens in a jet engine of a plane or a rocket. The hot gas from the engine is ejected backward with great velocity, in response the plane or rocket moves forward.

Example: A chair can exert a maximum reaction force of 525 N. If your mass is 50 Kg and your friend's mass is 55 Kg, can you stand up on this chair?

Solution: Your weight = 50 x 9.8 = 490 N

Weight of your friend = 55 x 9.8 = 539 N

Here, the weight will act as the action of standing up on the chair.

That is, the chair must also react with a force exactly equal to the weight.

Now, 490 N < 525 N, means you can stand up on the chair.

Again, 539 N > 525 N, means your friend will not be able to stand up on the chair, the chair will break.

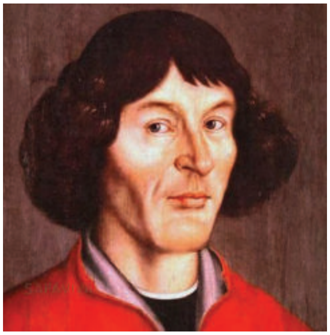
1.5 Gravitational Force

We have got an idea about force from Newton's laws of motion. We have discussed four types of fundamental forces but have not yet been introduced to any of them. Newton first mathematically introduced us to one of these four fundamental forces with his laws of gravitation. Now we can discuss the gravitational force as an example of a specific force.

1.5.1 From Information to Law

Many inquisitive people on Earth have long looked at the sky night after night, trying to understand the movements of the planets and stars. Intelligent people have drawn parallels between the movements of the planets from these observations. Many have discovered the relationship of the positions of the planets with the possible timing of seasonal changes or various natural events. Gradually observation became an important part of science. However, it is not enough to observe in isolation; if you want to use it or find a mathematical formulation, you need well-organized complete information.

Tycho Brahe was a Danish astronomer (Figure 1.8). He observed the sky night after

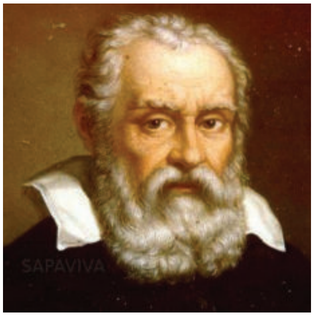


Nicolaus Copernicus
1473-1543

Tycho Brahe
1546 - 1601

Johannes Kepler
1571-1630

night for information and recorded the positions of the planets in a notebook at various times. By the time Nicolaus Copernicus spoke of a heliocentric solar system, Tycho Brahe accepted it as true for other planets but did not believe it applied to Earth! Tycho Brahe collected a large amount of correct data but did not have the opportunity to analyze it. After his death, the notebook passed to his associate astronomer Johannes Kepler. Kepler analyzed this vast amount of data and derived three mathematical formulas for the motions of all the planets as heliocentric. In this way, through observation and mathematical formulas, people came to know the fact that the planets and stars in the sky are also subject to certain scientific rules.



Galileo Galilei
1564-1642

Isaac Newton
1542-1727

Figure 1.8: Five important scientists of Astronomy

Kepler's theory explains how the planets revolve around the sun. Galileo, another contemporary scientist Galileo, experimentally proved that all objects fall to the ground 'simultaneously' due to the gravity of the earth, with the same rate of increase in velocity, that is, there must be a force behind it. These two apparently separate phenomena were united by the scientist Isaac Newton with the startling concept of the gravitational force

(Figure 1.9). That force can explain everything from the apple falling from the tree to the rotation of the planets around the sun.

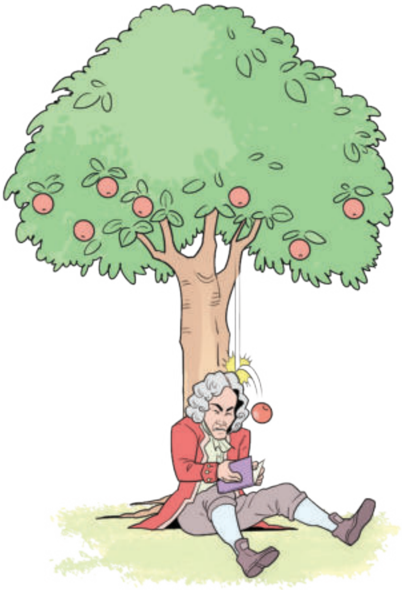


Figure 1.9 It is said that Newton discovered the explanation of the force of gravity by watching an apple fall while sitting under an apple tree.

1.5.2 Newton's Law of Gravitation: Definition and Explanation

- **Newton's Law of Gravitation:** Every particle attracts every other particle in the universe along the line intersecting both centres with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between their centers.

That is, two objects of mass m_1 and m_2 are located at a distance R, if the force between them is F, then mathematically,

$$F = G\frac{m_1\ m_2}{R^2}$$

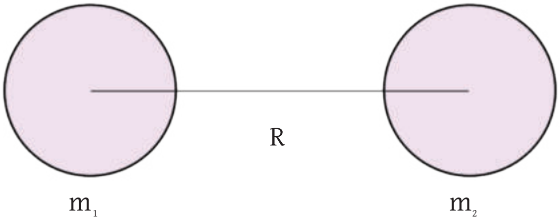


Figure 1.9: Gravitational Force between two masses

Here G is the gravitational constant, whose value is: 6.67 x 10^{-11} Nm^2kg^{-2}. Note that, here, the mass m_1 attracts the mass m_2 towards itself with F force and the mass m_2 attracts m_1 towards itself with the same (Fig. 1.9).

Example: How much will an object of mass 1 kg placed on the earth's surface attract the earth? (Earth mass $6x10^{24}$ kg and radius $6.4x10^{6}$ m)

Solution: According to Newton's law of gravitation

$$F = G\frac{Mm}{d^2} = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 1}{(6.4 \times 10^6)^2} = 9.8 \text{ N}$$

The earth will attract the object to itself with the same amount of force.

1.5.3 Concept of Weight

If one of the two masses is the earth during the gravitational force and if we assume its mass M and another object of mass m is placed on top of the earth then the earth will attract the mass m towards its center with the force F.

$$F= GMm/R^2$$

Actually, this force is the weight of the object. Remember that weight is not mass, weight is force. Here R is not the distance from the Earth's surface, but the distance from the center of the Earth to the mass m. Since the Earth's radius is large (about 6000 km), there is no need to take small elevations on the Earth's surface as a factor for now. (The distance from the center of the earth is measured because every point on the earth attracts m mass to itself, and if all the attractions are added together, it can be shown mathematically that all the mass of the earth is concentrated at the center of the earth.) Note here that the gravitational force of the earth is called gravity.

If an object of mass m is placed on the earth's surface, the gravitational force it will experience towards the center of the earth will cause an acceleration on the object according to Newton's second law. The acceleration due to gravity is written as g instead of a, so instead of F = ma we can write:

$$F = mg$$

$$\text{Or, } mg = GMm/R^2$$

$$\text{So, } g = GM/R^2$$

If we use earth's mass as $6x10^{24}$ kg, radius as 6.4x106 m and value of G as 6.67 x 10^{-11} $Nmkg^{-2}$, then,

$$g = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(6.4 \times 10^{6})^{2}} = 9.8\ ms^{-2}$$

Earlier this value was used for the acceleration due to gravity, now you must understand how this value is arrived at.

Example: You bought a 102 ml bottle of water from the store, what is the weight of the water?

Solution: Since the density of water is 1gm/ml, 102 ml of water is actually 102 gm of water = 0.102 kg of water.

So, weight of water = 0.102 x 9.8 = 1 N

That is, 1 newton of force means the weight of about 102 gm or 0.102 kg of water!

1.6 Pressure

A very important quantity/term related to force is pressure. This chapter has discussed various types of force, but has not specified exactly how the force should be applied. For example, you can push a stone with one hand, with both hands, or with your whole body (Figure 1.10). Even though you apply the same amount of force each time, the amount of pressure applied to the stone in these three cases will be different because the pressure is the force applied per unit area. That is, when force F is applied to a point of area A, the pressure P becomes

$$P = \frac{F}{A}$$

Figure 1.10: Pressure depends on the area where the force is applied

The unit of pressure is $\frac{N}{m^2}$ or Pa (Pascal). That is, 1 "Pa" (1 Pascal) of pressure is applied when 1 "N" force is applied to 1 m^2 area.

Example: Suppose your mass is 50 kg, the area of one side of your body is 0.5 m^2 and the area of the soles of both feet is 0.03 m^2. How much pressure will you exert on the floor if you lie down and how much pressure will you exert on the floor if you are standing?

Answer: Mass is 50 kg so weight is 50 ×9.8 N= 490 N

When lying down the Pressure is

$$P = \frac{490N}{0.5\ m^2} = 980\ \frac{N}{m^2}$$

When standing, the Pressure is

$$P = \frac{490N}{0.3\ m^2} = 16{,}333\ \frac{N}{m^2}$$

In other words, when lying down, the force is spread over a larger area, so less pressure is applied.

Just as applying force over a larger area produces less pressure, applying the same amount of force over a smaller area produces much greater pressure. The surface area of the sharp point of a nail is very small, so when it hits the wood or wall with force applied by hammering it, the nail head can easily drive into the wood or wall with a lot of pressure.

You know the force has a definite direction, but the pressure has no direction. This is very important to know, because the concept of pressure is much more important in liquids or gases than in solids. When a liquid or gas exerts pressure, it does not actually depend on direction.

1.6.1 Pressure in Liquids

All of you who have been in a pond, river or swimming pool have noticed that you can feel a kind of pressure when you go deeper into the water. It is very easy to find out exactly how much pressure can be felt when going deep into water or any other liquid.

Suppose you want to determine the pressure at a depth h of the liquid. Imagine a surface of area A there (Fig. 1.11). The weight of the column of liquid above it will exert a force on this surface A.

The volume of the liquid above the surface A is Ah. If the density of the liquid is ρ, then the mass of the liquid is m:

$$m=Ah\rho$$

Hence the weight or applied force

$$F = mg = (Ah\rho)g$$

So pressure:

$$P = \frac{F}{A} = \frac{Ah\rho g}{A} = h\rho g$$

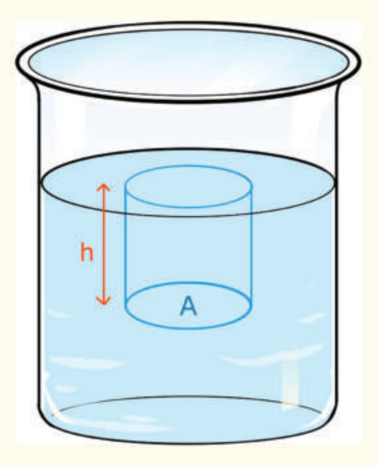


Figure 1.11: Pressure is created on the bottom surface for the height of the liquid

That is, pressure increases with the increase of depth in a liquid of a given density. In water, the pressure increases approximately every ten meters of depth, equal to the air pressure.

Example: Kerosene (800 kg m^{-3}), water (density 1000 kg m^{-3}) and mercury (density 13,600 kg m^{-3}). What is the pressure below 50 cm for these three liquids?

Answer: Pressure $P=h\rho g$

For Kerosene, P = 0.50 m × 800 kg m^{-3} × 9.8 N kg^{-1} = 3,920 N m^{-2}

For Water, P = 0.50 m × 1000 kg m^{-3} × 9.8 N kg^{-1} = 4,900 N m^{-2}

For Mercury, P = 0.50 m × 13,600 kg m^{-3} × 9.8 N kg^{-1} = 666,400 N m^{-2}

1.6.2 Archimedes' Principle and Buoyancy

You all must have heard of Archimedes' formula and the story behind it. The formula is simple; when an object is immersed in a liquid, the amount of liquid it displaces equals the weight of the object. We will now derive this formula. Figure 1.12 shows a cylinder immersed in some liquid. (It could have been any other shape instead of cylinder, we have taken cylinder for ease of calculation.)

Say the height of the cylinder is h and the cross-sectional area of the top and bottom is A. We imagine the cylinder is immersed in the liquid such that its upper surface has a depth h1 and its lower surface has a depth h_2.

Pressure in liquids (or gases) does not act in any particular direction. It works equally in all directions. Hence the amount of pressure acting downwards on the upper surface of the cylinder is

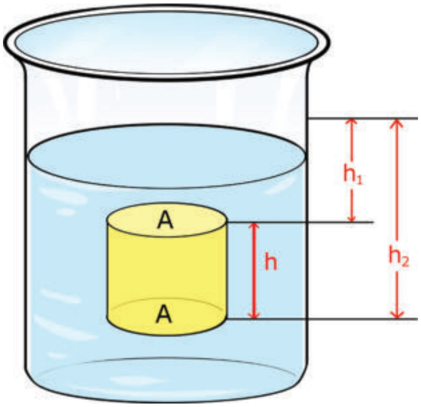


Figure 1.12: An object loses weight equal to the amount of liquid it displaces.

$$P_1 = h_1 \rho g$$

And the amount of pressure acting upwards on the lower surface of the cylinder is

$$P_2 = h_2 \rho g$$

Since,

$$P_1 = \frac{F_1}{A}$$

Therefore, force applied downward on the upper surface is $F_1 = AP_1 = Ah_1\rho g$

Similarly,

$$P_2 = \frac{F_2}{A}$$

Therefore, force applied upward on the lower surface is $F_2 = AP_2 = Ah_2\rho g$

We don't need to worry about how much force is applied to the side surfaces of the cylinder, because the force that the cylinder feels on one side is exactly the opposite of the force on the other side, and they cancel each other out.

Since the value of h_2 is greater than h_1 we can see that the value of F_2 is greater than F_1. So the total force will be upward and amount to:

$$F = F_2 - F_1 = A(h_2 - h_1)\ \rho g$$

$$F = Ah\rho g$$

Since Ah is the volume of the cylinder, ρ the density of the liquid and g the acceleration due to gravity, the upward force is equal to the weight of the liquid equal to the volume of the cylinder. It is exactly what is known as Archimedes' law. This upward force is called ‘Buoyancy’.

1.6.3 Floating or Sinking of Objects

Now you must have understood why one object floats and another sinks. You know that when an object is immersed in water, due to buoyancy it experiences a force equal to the weight of the water displaced above it. If that force is greater than the weight of the object, the object will float. It will only sink that much the weight of which equals to the amount of displaced water, the rest will not sink in the water.

If the weight of the object is greater than the weight of the water it displaces, it will sink. However, when submerged in water, its weight will seem less than its actual weight.

If somehow the weight of the object can be made exactly equal to the weight of the displaced water, then the object will stay in the water wherever it is placed, neither floating nor sinking. Although not seen in everyday life, it is routinely done in submarines to navigate underwater.

Example: If a piece of wood is floated in water, what percentage of it will be submerged? (Density of wood $\rho = 0.5 \times 10^3$ kg/m^3 Density of water $\rho_W = 10^3$ kg/m$_3$)

Answer: For the wood to float, the weight of the submerged part of the water must be equal to the weight of the wood. That is, if the volume of wood is V, its weight is Vρg, and if V_1 part of the wood is submerged in water, then the weight of that amount of water is $V_1 \rho_W g$, so

$$V\rho g = V_1 \ {}_{w} g \quad \text{or} \quad V\rho = V_1 \rho_w$$

$$\frac{V_1}{V} = \frac{}{\rho_w} = \frac{0.5\times\ 10^3\ \mathrm{kg/m^3}}{10^3\ \mathrm{kg/m^3}} \times 100 = 50\%$$

1.7 Energy

In the previous grade, we have already known the examples of different forces. We also know that energy is the ability to do work. But here we do not mean the work that we do in our daily life, the word ‘work’ has a specific meaning in the language of science. Here we will discuss the relationship between energy and work.

1.7.1 Kinetic and potential energy

Work is said to be done if an object can be moved a certain distance in the direction of the force by applying the force. If an object is moved s distance in the direction of the force by a force F, then the amount of work done is,

$$W = Fs$$

The unit of work is joule (J); 1 J of work is done when an object is moved 1 m by applying a force of 1 newton.

From Newton's second law we know $F = ma$, so we can write,

$$W = mas$$

We know from the equation of motion,

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

If the object starts from rest then initial velocity $u = 0$,

$$\text{Then} \quad v^2 = 2as$$

$$\text{and} \quad as = \frac{v^2}{2}$$

So the amount of work will be, $W = mas$

$$W = \frac{1}{2} mv^2$$

which is actually the kinetic energy of an object. That is, when work is done on an object, that work is converted into kinetic energy. We don't always see that in real life. Because the frictional force acts in the opposite direction and sometimes converts the energy into heat, sound, etc. instead of converting into kinetic energy.

Not only can kinetic energy be created by doing work, but that work can also be stored as potential energy. If you want to lift an object up, you must apply an upward force equal to the weight of the object. If an object of mass m is lifted to a height h by an upward force F = mg equal to the object's weight, the amount of work done will be:

$$W = Fh$$

Or $$W = mgh$$

After the object is raised to a height h, since it remains at rest, there is no kinetic energy in it, it has not been converted into any other energy such as heat or sound due to friction, so this mgh amount of work energy must have actually been stored as potential energy. We can understand this when we see that when the object is released from a height h, it gains momentum as it falls downwards, and the stored potential energy is converted into kinetic energy.

1.7.2 Conservation of Mechanical Energy

In the previous grade we learned about 'conservation of energy'. According to this principle, energy is neither created nor destroyed, only transformed from one form to another. Kinetic energy and potential energy together are called 'mechanical energy'. If the energy does not change in any way other than mechanical energy, the total amount of mechanical energy must remain the same. We can call this the 'conservation of mechanical energy'. If we lift an object some distance and drop it, it will continue to move. In the beginning the object has no motion, so it is all potential energy. A little later the potential energy will decrease when the altitude decreases, while the speed will increase so the kinetic energy will increase. In this way, when it comes down to the very bottom, it will be entirely kinetic energy. That is, as much potential energy is consumed, that much kinetic energy is gained. This is the conservation of mechanical energy!

Example: An object is dropped from point A in the figure (Fig. 1.13). What is the total energy of the object at points A, B and C?

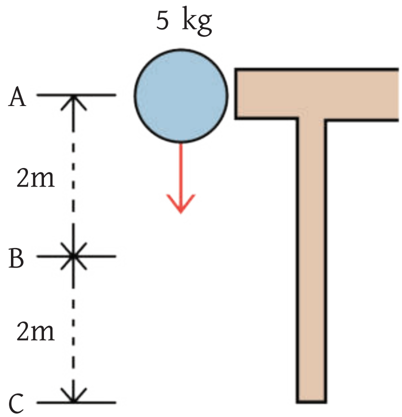


Figure 1.13: An object of 5kg mass is dropped from a table of 4m height

Solution:

At point A

Potential Energy $mgh = 5 \times 9.8 \times 4 = 196$ J

Kinetic energy $\frac{1}{2} mv^2 = \frac{1}{2} \times 5 \times 0^2 = 0$ J

Total energy $mgh + \frac{1}{2} mv^2 = 196 + 0 = 196$ J

At point B

Potential Energy $mgh = 5 \times 9.8 \times 2 = 98$ J

Since the kinetic energy is $\frac{1}{2} mv^2$ we need to find the value of v^2

We can derive it from the formula $v^2 = u^2 + 2as$

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

or, $v^2 = 0^2 + 2 \times 9.8 \times 2$

or, $v^2 = 39.2 \text{ ms}^{-1}$

Kinetic energy $\frac{1}{2} mv^2 = \frac{1}{2} \times 5 \times 39.2 = 98$ J

Total energy $mgh + \frac{1}{2} mv^2 = 98 + 98 = 196$ J

At point C

$mgh = 5 \times 9.8 \times 0 = 0$ J

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

or, $v^2 = 0^2 + 2 \times 9.8 \times 4$, or, $v^2 = 78.4 \text{ ms}^{-1}$

Kinetic energy $\frac{1}{2} mv^2 = \frac{1}{2} \times 5 \times 78.4 = 196$ J

Total energy $mgh + \frac{1}{2}mv^2 = 0 + 196 = 196$ J

That is, we have calculated in a specific example that the conservation of mechanical energy is indeed maintained. When something is dropped from a height, how the potential energy and kinetic energy change with height but the total energy does not change is shown in the adjacent graph (Figure 1.14).

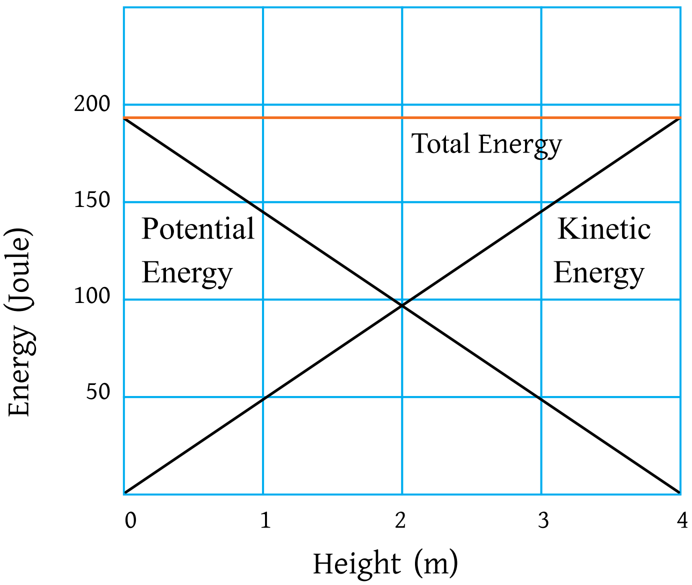


Figure 1.14: As potential energy decreases, kinetic energy increases but total energy remains unchanged.

Food for thought

- What would this graph look like if it were drawn with time instead of height?

Chapter 2

Temperature and Heat

Chapter 2

Temperature and Heat

This chapter discusses the following topics:

☑ Temperature and internal energy
☑ Expansion of solids, liquids, and gases on application of heat
☑ Change of state on application of heat
☑ Calorimetry
☑ Thermodynamics

Heat

Around us, we see various types of energy, which we use in our daily lives. Heat is one such energy. We are all familiar with this energy in our lives and have used it in various ways. We use heat to cook, heat water for tea or coffee, and dry clothes quickly by hanging them in the sun. Sometimes, we try to protect ourselves from excessive heat for personal comfort, sit in the shade to protect ourselves from the sun, and avoid wearing black clothes during hot weather. This list can be much longer. So, it is natural that we are all curious about how this heat energy came to be. Or, in other words, why is heat energy present in hot water but not in cold water? This is something we all need to know.

At one time, scientists had many questions about this matter, but now we know that all substances are made up of atoms and molecules, and we see the motion or vibration of these atoms and molecules as heat energy. The more these atoms and molecules move, the hotter they will feel. The atoms of water inside a glass of cold water are not stationary, they are also moving. But when heat is applied, the atoms of that water move much more. If more heat is applied, it is possible for the velocity of some water molecules to increase so much that they become free from the water. We call this process evaporation.

Heat Transfer

We need to transfer or conduct heat from one place to another for various purposes. Heat is transferred in three ways: conduction, convection, and radiation.

Conduction

Heat is conducted through the vibration of atoms of a solid substance. When one end of a solid substance is heated, the atoms at that end vibrate. If an atom vibrates, it starts to make the adjacent atoms vibrate too. That atom then vibrates its neighboring atoms. In this way, the vibration is transmitted from one end of the solid substance to the other. This process is called heat conduction.

Convection

When a fluid or gas is heated, it becomes less dense and rises because its molecules move faster and take up more space. If the same amount of fluid or gas is kept in a slightly larger space, its density decreases or it becomes lighter and rises. The cooler fluid or gas nearby then takes its place. This way, an internal circulation of fluid or gas starts, which mixes all the fluid or gas very well and heats it up.

Radiation

When we stand in the sun, the heat we feel is not transported to us by convection or conduction, but by radiation from the sun. Radiation does not require a medium, so even though the Sun and Earth remain in space, visible light and invisible infrared and ultraviolet rays can reach Earth through radiation.

Specific Heat

The amount of heat stored in an object depends on the object's temperature, its mass, and its specific heat. Since air has a very low density, it has a very low capacity to store heat. A substance with a low specific heat can be heated to a much higher temperature by giving off little heat. On the other hand, if a substance has a high specific heat, a lot of heat must be given off to bring it to the same temperature.

Heat Flow

When two objects with different temperatures come into contact, heat flows from the object with a higher temperature to the object with a lower temperature. For that reason, temperature is often defined in terms of heat flow. Heat will continue to flow until the two temperatures reach the same point.

If a needle is heated by fire, the amount of heat inside it will not be much. In comparison, a bucket full of water will contain much more heat. However, if the hot needle is dropped into water, even though the amount of heat in the ball is low, it will still transfer its heat to the water in the bucket.

2.1 Temperature and Internal Energy

To know heat energy correctly we need to have a clear idea about temperature. Because the internal energy stored inside any object due to heat has a relationship with temperature.

2.1.1 Thermal energy

Heat is one of our most familiar and necessary forms of energy. In our daily lives we regularly generate heat, use heat, and sometimes try to remove excess heat. The creation and control of heat has played a major role in the current civilization of the world. Heat is generated by the use of fuel in vehicles and the heat energy is converted into mechanical energy to drive the vehicles. In power plants most of the time, electricity is generated by turning generators using thermal energy. When using nuclear energy, it is available as thermal energy. Availability of the right thermal energy also played a major role in the development of life on Earth. Living organisms also consume food to survive and first convert it into heat energy. Unfortunately, humans misuse energy and create unnecessary heat in the world, changing the climate of the whole world and putting the people of the world at risk of danger.

Since heat is energy, naturally the unit of heat like any other energy is joule (J). Another unit of heat is the calorie (cal). The amount of heat required to raise the temperature of 1 gram of water by 1 degree Celsius is known as calorie. 1 calorie contains 4.2 J of heat.

2.1.2 Motion of Molecules and Temperature

Apparently, thermal energy seems to be a completely different type of energy from mechanical energy, but this energy comes from the combined kinetic energy or vibrational energy of the molecules of matter. In the case of solids, heat is the vibration of molecules. In the case of liquids, it means that the molecules move in contact with each other. In the case of gases, it is the free movement of molecules relative to one another. To understand heat energy we must first understand what temperature is. Heat is a quantity of energy and temperature is a measure of how hot or cold something is. Therefore, from a molecular point of view, temperature can be said to be a measure of the vibration or kinetic energy of the molecules of matter. The higher the speed or vibration of the molecules, the higher the temperature of the object.

The international unit of temperature is Kelvin (K), but the unit we use most for temperature in our daily life is Celsius (°C). If you compare the Celsius and Kelvin scales, you will see that there is no difference in the Kelvin scale except for the addition of 273.15° to the Celsius scale temperature. The Kelvin scale is developed to take this absolute zero temperature as zero degrees. In Celsius scale, this temperature is -273.15° so adding 273.15 to Celsius scale gives Kelvin scale. In addition to the Celsius scale, another temperature scale called Fahrenheit is used in some countries and in thermometers to measure fever. On that scale the temperature of ice is 32°F and the temperature of boiling water is 212°F.

Mathematically, the relationship between these three temperatures is:

$$\frac{T_C}{100} = \frac{T_K - 273.15}{100} = \frac{T_F}{180}$$

2.1.3 Concept of Internal Energy

Particles (atoms or molecules) in solids, liquids, and gases have kinetic energy because they are in motion. They also have potential energy because molecular bonds try to hold the particles together. Gas particles have the highest kinetic energy as they are almost free. The total kinetic energy and potential energy of all the particles of a substance is called its internal energy. The higher the temperature of an object, the more its particles move, so the internal energy increases.

In general, we may think of energy as flowing from higher energy to lower energy. But a bucket of water has much more heat energy than a hot needle. If we submerge the heated needle in water, a small amount of thermal energy from the needle will go into the bucket of water. That's because heat energy flow doesn't depend on heat energy, it depends on temperature difference. If a hot object comes in contact with a cold object, the hot object cools by losing internal energy, and, simultaneously, the cold object gains internal energy and becomes hot. Heat energy will continue to flow until the temperature of the two objects is equal. This transferable energy between objects due to temperature difference is known as heat or thermal energy.

When a hot object is placed in contact with a cold object, the particles of that object lose kinetic energy as heat energy is transferred from the hot object to the cold object. Again, as the cooler object heats up its particles gain kinetic energy. When the two objects reach the same temperature, this transfer of energy stops as the average kinetic energy of each particle becomes equal. The higher the temperature, the higher the average kinetic energy of the particles.

Figure: 2.1 (above) Gap between rail lines. (below) Crooked lines because of hot weather

2.2 Thermal Expansion of Matter

If we take a closer look at the rail lines, we see that there is always a slight gap between them. This is because heat causes expansion in the rail line, causing the rail line to become crooked (Figure 2.1). In order to know exactly how much clearance in the rail lines will always be safe for trains, we need to understand the relationship between heat and expansion of matter.

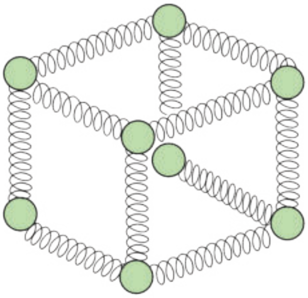


Figure 2.2: Spring model of molecules of matter

2.2.1 Expansion in Solids

You already know about the change in temperature of matter and the vibration or speed increase and reduction of the molecules with the application of heat. In solids, molecules hold each other in fixed positions by molecular forces. We can compare this force with the spring shown in Figure 2.2. But this spring is a special kind of spring, one that stretches farther but contracts less—because one molecule doesn't let another molecule get too close. When heat is applied, the molecules vibrate more, they move a little farther during expansion but less distance during compression, so the vibrating molecules take up more space and the volume of the substance appears to have increased. When heat is applied, solids expand in all three directions: length, width, and height. Therefore, to measure expansion in solids, three quantities are used namely linear, area, and volume expansion coefficient. Because they are interrelated, by measuring any one we can get the other two.

Linear expansion coefficients are used to measure the expansion of a material along its length only. It is expressed by the Greek letter α (pronounced alpha). That is, α is how much a substance increases in length for every degree of temperature increase. Suppose, the length of a solid at temperature T_1 is L_1 and on increasing the temperature to T_2 the length of the object becomes L_2.

Then the total change in length is: $L_2 - L_1$

How much length has changed $\frac{(L_2 - L_1)}{L_1}$

Change in length per degree rise in temperature: $\frac{(L_2 - L_1)}{L_1 (T_2 - T_1)}$

So, linear expansion coefficient α is,

$$\alpha = \frac{(L_2 - L_1)}{L_1 (T_2 - T_1)}$$

That is, if we know the linear expansion coefficient α of a solid object, from this equation we can find out the length of an object if the temperature increases. If the length of a solid at temperature T_1 is L_1 then if its temperature is increased to T_2 the length of the object will be L_2

$$L_2 = L_1 + \alpha L_1 \; (T_2 - T_1)$$

Example: A 10 m length of metal wire at a temperature of 290 K is exposed to the sun and its temperature rises to 325 K. Now what will be the length of the wire? (Linear Coefficient of wire material is $23 \times 10^{-6} K^{-1}$)

Solution: Expanded length $L_2 = L_1 + \alpha L_1 (T_2 - T_1) = 10 + 23 \times 10^{-6} \times 10 \times (325 - 290) = 10.008 \text{ m}$

The area expansion coefficient is used to measure the expansion along the surface area of an object. It is expressed by the Greek letter β (pronounced beta). If an object of temperature T_1 and area A_1 changes into temperature T_2 and area A_2, then

$$\beta = \frac{(A_2 - A_1)}{A_1 (T_2 - T_1)}$$

Similarly, the volumetric (or cubical) thermal expansion coefficient is used to measure the volume expansion of a material. The volumetric expansion coefficient is expressed by the Greek letter γ (pronounced gamma). If the temperature of an object of temperature T_1 and volume V_1 changes to T2, then if the volume changes to V_2

$$\gamma = \frac{(V_2 - V_1)}{V_1 (T_2 - T_1)}$$

But interestingly, if the linear expansion coefficient α is known, there is no need to measure the area expansion coefficient β or the volumetric expansion coefficient γ separately, because:

$$\beta = 2\alpha$$

$$\gamma = 3\alpha$$

Do it yourself:

To find out the area expansion coefficient, assuming the area of the solid to be square, we can write for A_1 and A_2:

$$A_1 = L_1^2$$

$$A_2 = L_2^2 = \{L_1 + \alpha L_1 (T_2 - T_1)\}^2$$

Since the value of linear expansion coefficient α is very small, the value of α2 is much smaller, so let α^2 be zero and $\beta = 2\alpha$ ।

Do it yourself:

Similarly, to find the volumetric coefficient of expansion, assuming a cube for the volume of solid, we can write for V_1 and V_2:

$$V_1 = L_1^3$$

$$V_2 = L_2^3 = \{L_1 + \alpha L_1(T_2 - T_1)\}^3$$

Since the value of linear expansion coefficient α -is very small, the values of α^2 and α^3 -are much smaller, so let α^2 and α^3 be zero and show $\gamma = 3\alpha$ ।

Example: A square metal sheet of 5 cm length at 275 K is heated to 350 K. Now how much will the area of the sheet increase? (linear expansion coefficient of sheet material $\alpha = 22 \times 10^{-6}\ K^{-1}$)

Solution: Since the linear expansion coefficient $\alpha = 22 \times 10^{-6}\ K^{-1}$

So area expansion coefficient $\beta = 2\alpha = 2 \times 22 \times 10^{-6} = 44 \times 10^{-6}\ K^{-1}$

Here, the initial area is $A_1 = 5 \times 5 = 25\ cm^2$

Changed area $A_2 = A_1 + \beta A_1 (T_2 - T_1)$

That is, the change in area $A_2 - A_1 = \beta A_1 (T_2 - T_1) = 44 \times 10^{-6} \times 25 \times (350 - 275) = 0.0033\ cm^2$

Example: The density of gold is 19.30 gm/cc, iand ts linear expansion coefficient is $14{\times}10^{-6}\ {}^0C^{-1}$-What will be the density if the temperature is raised to 100^0C?

Answer: Density, $\rho = \frac{m}{v}$

where V is volume and m is mass. Increasing the temperature increases the volume even though the mass remains the same. So if the temperature is raised to 100^0C its volume V' will be:

$$V' = V + \gamma V(T_2 - T_1) = V(1+3\alpha \times 100)$$

$$\alpha = 14 \times 10^{-6}\ {}^0C^{-1}$$

$$V' = V(1 + 4.2 \times 10^{-3})$$

$$\rho' = \frac{m}{V'} = \frac{m}{V(1+4.2\times 1\ 0^{-3})} = \frac{m}{V} \times 0\ .9958 = 0\ .9958\rho$$

$$\rho' = 0\ .9958 \times 19.30\ \text{gm/cc} = 19.22\ \text{gm/cc}$$

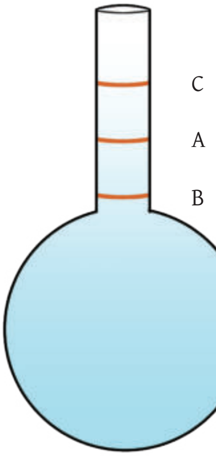


Figure 2.3: Apparent and Real expansion of liquids

If the coefficient of expansion of a substance is known, the extent to which it will change with changing temperature can be calculated. Knowing the expansion coefficient is very important in various practical applications. You already know that since railway lines expand with heat, it is necessary to calculate in advance how much free space is required for this. Otherwise, the railway line may bend and cause an accident. It is also necessary to know the coefficient of expansion while making engines or such machines, because these machines have a lot of temperature fluctuations. Again, rockets or artificial satellites heat up as they move at high speeds through the atmosphere. Here too the expansion coefficient needs to be known. The expansion coefficient of the material that dentists use to repair tooth decay must be exactly the same as the expansion coefficient of the tooth. Otherwise, it will be disjointed by being smaller when eating something cold, or expand more when eating something hot and put pressure on the tooth.

2.2.2 Expansion in Liquids

Liquids have no length or area, only volume. So expansion of a liquid means the expansion of its volume. However, one has to be careful when measuring the expansion of a liquid because the liquid always needs to be kept in a container. So when the liquid is heated to measure expansion, the container also heats up and the container also expands a bit. So the expansion seen in the liquid kept in the container is not the real expansion, it is the apparent expansion. If the expansion of the liquid is calculated taking into account the expansion of the container, it will be the real expansion or absolute expansion (Figure 2.3).

If a glass container with a narrow tube is filled with liquid up to mark A and heated, we see that the height of the liquid first drops to B. This will happen because after heating, the temperature of the container will increase before the temperature of the liquid increases and it will expand, i.e. the volume of the container will increase slightly. If we continue to heat it, the height of the liquid will eventually rise. Since the expansion of the liquid is high, we will see the liquid pass A and finally reach height C. By multiplying the cross-section of this part of the container by the height CB we get the actual expansion of the liquid.

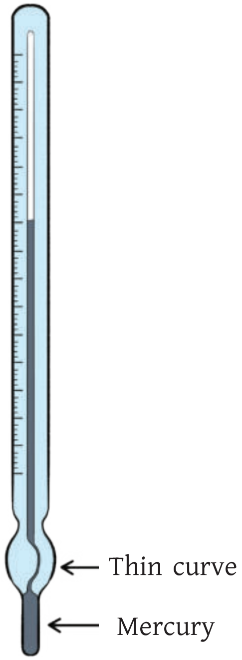


Figure 2.4: Expansion of mercury in thermometer

The simplest example of the expansion of a liquid is the mercury or alcohol thermometer. There are different types of thermometers, of which the fever thermometer is probably the most familiar to you. At the base of this thermometer is mercury in a glass tube. When heated, the mercury expands and rises in a very narrow tube (Figure 2.4). Temperature is measured by seeing how much mercury has risen in the marked thermometer. A very narrow bend is placed at the base of the narrow tube so that the mercury does not fall down after it is removed from the body. For this reason, once it expands and goes up, it cannot come down even after the temperature drops, it has to be shaken down.

Example: 4 L of water at 280 K is heated to 360 K. Now if the volume of water is 4.0672 L, what is the coefficient of volume expansion of water?

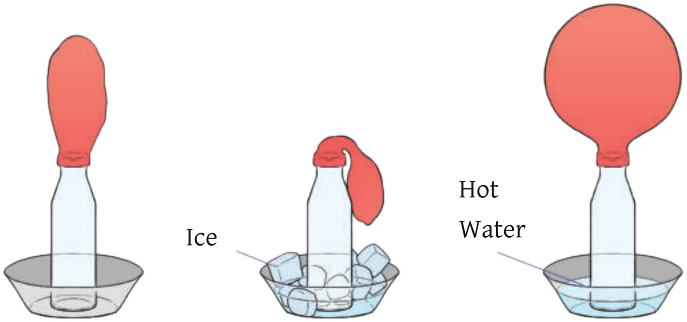


Figure 2.5: The air inside the balloon compresses when cooled and expands when heated.

Solution: Volumetric expansion coefficient

$\gamma = (V_2 - V_1)/\{V_1 (T_2-T_1)\}$

$= (4.0672 - 4)/\{4 (360-280)\}$

$= 2.1 \times 10^{-4} K^{-1}$

2.2.3 Diffusion of gaseous substances

Since solid matter has both shape and volume, there is no problem understanding the expansion. Even though a liquid has no definite shape, it has volume, so we can see or measure its expansion. In the case of gas, the matter is slightly different because not only does it have no definite shape, but it also has no definite volume. A gas will immediately take up the volume of the container into which it is inserted. We do not see much of the expansion of solids and liquids in our daily life as it is quite low. Compared to that, the expansion of gas is much higher as we can see from simple experiment. If a balloon is inflated a little and placed in the mouth of a bottle and the bottle is immersed in ice water, the balloon will shrink, and if the bottle is immersed in hot water, the balloon will be inflated (Figure 2.5).

In the case of solid or liquid we did not have to worry about the pressure applied to them, but in the case of gas the pressure is very important. Neither liquids nor solids can be greatly compressed by pressure. But gases can be compressed much more easily by pressing them. If the same amount of gas is placed in a container of different volume, its pressure also becomes different, that is, the expansion and contraction of the gas can be done by increasing or decreasing the pressure just like temperature. So if we want to measure how much the volume of a gas has increased with heat, we have to make sure that there is no change in its pressure (Figure 2.6). So first we need to know the relationship between pressure (P), volume (V) and temperature (T) of a given amount of gas. Remember, here T is temperature in Kelvin scale. This is called the

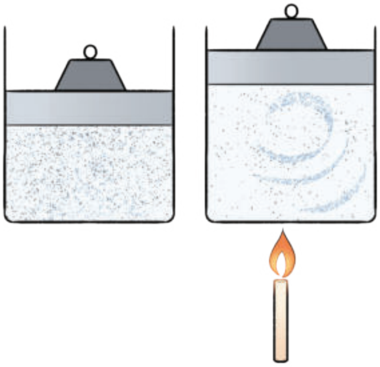


Figure 2.6: Heat increases the pressure and volume of a gas

ideal gas law and mathematically the formula can be written as:

$$PV = nRT$$

Here R is the 'universal gas constant', its value is 8.314 $JK^{-1}mol^{-1}$ and n is the amount of gas per mole unit. The value of this constant is true for all gases.

Example: If 128 g of oxygen gas is kept in a 100 ml container at a pressure of 108 Pa, what will be its temperature?

Solution: Pressure P = 10^8 Pa, Volume V = 100 ml = 10^{-4} m^3, Molecular mass of oxygen is 32 g, so 128 g oxygen means

$$n = 128/32 = 4 \text{ moles of oxygen}$$

$$\text{Since , } PV = nRT$$

$$\text{So } T= PV/nR = (10^8 \times 10^{-4})/ (4 \times 8.314) = 300K$$

On the Celsius scale this temperature is $300 - 273 = 27^0C$

The result would have been the same for 4 moles of hydrogen or 4 moles of nitrogen or 4 moles of any gas.

We can now find the expansion coefficient for the gas. We know that at a given pressure, if a certain volume of gas at temperature T_1 is V_1 and at temperature T_2 the volume of the same gas is V_2 then its expansion coefficient will be,

$$\gamma = \frac{(V_2 - V_1)}{V_1 (T_2 - T_1)}$$

But we know $PV_1 = nRT_1$

$$PV_2 = nRT_2$$

Therefore, $P(V_2 - V_1) = nR(T_2 - T_1)$

Since $PV_1 = nRT_1$ dividing the left side by PV_1 and the right side by nRT_1

$$(V_2 - V_1)/V_1 = (T_2 - T_1)/T_1$$

Or, $$\frac{(V_2 - V_1)}{V_1 (T_2 - T_1)} = \frac{1}{T_1}$$

Therefore, $$\gamma = \frac{1}{T_1}$$

You see the expansion coefficient of a gas is not a constant number, it is inverse of temperature. The lower the temperature, the greater the expansion of the gas.

2.4 Calorimetry

Although heat, temperature and related topics have been discussed, how to measure the total heat of an object, or how much heat must be applied to an object to increase its temperature by a certain amount has not yet been discussed. The branch of science which deals with the method of measuring heat is called calorimetry.

How much heat is inside an object depends on three factors. One is the mass of the object, as all of you who have heated water in a kettle know. You have seen that it takes much more heat to boil a whole bottle of water than it does to boil a cup of water in a kettle. The second thing is 'temperature', we all can guess that too. Because we have seen that a little heat in the kettle warms the water a little, but a lot of heat over time increases the temperature a lot. So with daily life experience, we can say that more mass and more temperature have more heat inside it.

The third factor that the heat of an object depends on is the relative heat which we cannot accurately estimate from our daily life experience. For example, heating some water by 10 °C will bring it to a comfortable temperature. But an equal amount of heat applied to a piece of iron will raise its temperature by about 100 °C, i.e. it will be too hot to touch. In the language of science, since the specific heat of water is ten times higher than the specific heat of iron, water needs to be heated ten times more to reach the same temperature as iron.

» The amount of heat required to raise the temperature of 1 kg of a substance by 1°C is the specific heat of that substance.

That is, if heat Q is required to raise a substance of mass m from temperature T_1 to T_2, and the specific heat of the substance is s:

$$Q = m\ (T_2 - T_1)\ s$$

The unit of specific heat is $Jkg^{-1}\ {}^0C^{-1}$ on the Celsius scale and $Jkg^{-1}K^{-1}$

Example: If the specific heat of glass is 840 J $kg^{-1}K^{-1}$, how much heat is required to raise the temperature of 3 kg of glass by 30 K?

Solution: Heat required $Q = m\ s\ (T_2 - T_1) = 3 \times 840 \times 30 = 71280$ J

Example: 2 Kg of water at 300 K is placed on a stove and its temperature rises to 310 K. What is the specific heat of water if 84000 J of heat is obtained from the stove?

Solution: Heat $Q = m\ s\ (T_2 - T_1)$

That is, relative heat $s = Q / \{ m\ (T_2 - T_1)\} = 84000 / \{ 2\ (310 - 300)\} = 4200$ J $kg^{-1}K^{-1}$

Example: If 5 kg of water at 295 K is heated at 63000 J, what will be the temperature of the water?

Solution: Heat $Q = m\ s\ (T_2 - T_1)$

That is, the temperature change $T_2 = T_1 + Q/ms = 295 + 63000/(5 \times 4200) = 298$ K

The heat capacity C of a substance is defined as how much heat is required to raise the temperature of that substance by 1K. The heat capacity C of any object can be easily calculated if the mass and specific heat of the object are known, because if the mass of the object is m, and the specific heat is s, then the capacity of the object is:

$$C = ms$$

Example: What is the heat capacity of 10kg of water compared to 10kg of iron? (specific heat of iron 450 $Jkg^{-1}K^{-1}$, , specific heat of water 4200 $Jkg^{-1}K^{-1}$)

Solution: Heat capacity of iron: $C = ms = 10 \times 450 = 4500\ Jkg^{-1}K^{-1}$

Heat capacity of water: $C = ms = 10 \times 4200 = 42000\ Jkg^{-1}K^{-1}$

So, we see that the heat capacity of water is about ten times greater than the heat capacity of iron.

Principles of Calorimetry

Many a times we pour some boiling hot water in a bucket of cold water for bathing in winter. The boiling hot water cools to give heat to the cold water in the bucket and at the same time the cold water in the bucket heats up to take heat from the hot boiling water. At some point the temperature of the hot water drops and the temperature of the cold water rises until the entire water is at a usable temperature. It is very easy to figure out how much heat will be given or absorbed by mixing a substance of one temperature with a substance of another temperature and what temperature will be reached in the end. This phenomenon obeys two rules, which can be understood from the bucket example above. Both of these rules are the principles of calorimetry:

(1) An object of higher temperature will continue to transfer heat to an object of lower temperature until the temperature of the two objects is equal.

(2) As much heat is given off by a hot object, a cold object absorbs as much heat.

Example: A 5 kg piece of hot iron at 400 K is dropped into 2 kg of water at 300 K. What will be the temperature after some time? (Specific heat of iron is 450 J $kg^{-1}K^{-1}$)

Solution: Since the temperature of the water is lower and the temperature of the iron is higher, heat exchange will continue until the two reach the same temperature. Suppose, this temperature is T_1 then the temperature of water will increase to T and the temperature of iron will decrease to T_2.

So, the heat required to heat the water is $Q_1 = m_1 s_1 (T - T_1)$

Again, the heat leaving the iron to cool is $Q_2 = m_2 s_2 (T_2 - T)$

According to the principle of calorimetry, $Q_1 = Q_2$.

That is, $m_1 s_1 (T - T_1) = m_2 s_2 (T_2 - T)$

So, $2 \times 4200 \times (T - 300) = 5 \times 450 \times (400 - T)$

Or, $T = 321.13$ K

2.5 Effect of Heat on Change of State of Matter

As you already know, all matter is made of molecules and in solids the molecules hold each other in place. When heat is applied, their vibrations increase and the molecular bonds loosen and they move over each other and this is what we call a liquid. If the temperature rises further, the molecules break free and begin to move, which we call gases. However, heating certain solids can directly convert them into gases. These changes are physical changes, so it is possible to change the opposite of these three states by removing heat. Figure 2.7 shows the changes in these three states of matter by the application of heat.

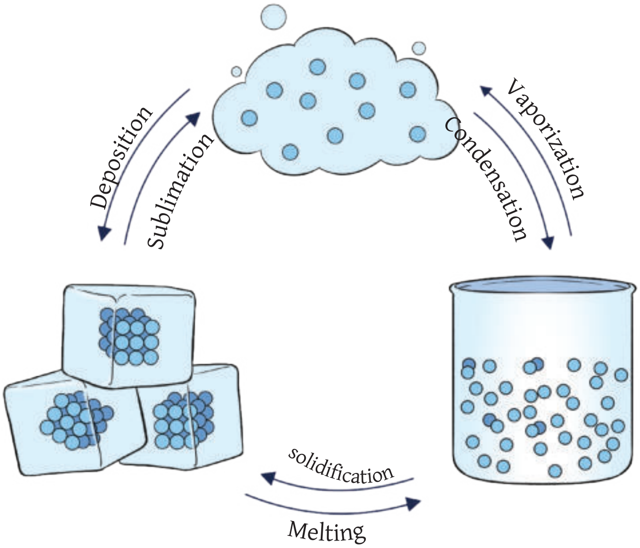


Figure 2.7: Heat exchange can convert matter into three states: solid, liquid, and gas.

Solid to Liquid and Liquid to Solid: When a solid is heated, its temperature increases. When the temperature reaches a certain value, the solid starts to melt. This process is called ‘melting’. When we leave a piece of ice outside, it melts by absorbing heat from the surrounding air. The temperature at which melting begins is called the ‘melting point’. The melting point of ice is 0 degrees Celsius. The reverse process of solid-to-liquid conversion with heat also occurs. Removing heat can cause a liquid to solidify. The transformation from liquid state to a solid state is called solidification. Molten wax that drips from a burning candle cools and solidifies, an example of solidification.

Liquid to Gas and Gas to Liquid: Heating a liquid causes its temperature to rise and as the temperature rises, at one time the liquid changes to a gas. This process is called ‘vaporization’ and the temperature at which vaporization occurs is called boiling point. The boiling point of water is 100 degrees Celsius. The reverse process of liquid-to-gas conversion with heat also occurs. A gas can become a liquid if heat is removed. If we put a few pieces of ice in a glass, we can see that the water vapor cools down on the glass and collects as water droplets. This conversion from gaseous state to liquid state is called condensation.

Solid to Gas and Gas to Solid: The process in which heat is applied to a solid substance, and instead of turning into a liquid, it directly turns into a vapor, is called ‘sublimation’. We have seen naphthalene used in clothes to repel insects. When solid naphthalene is heated, it turns directly into a gaseous substance rather than a liquid.

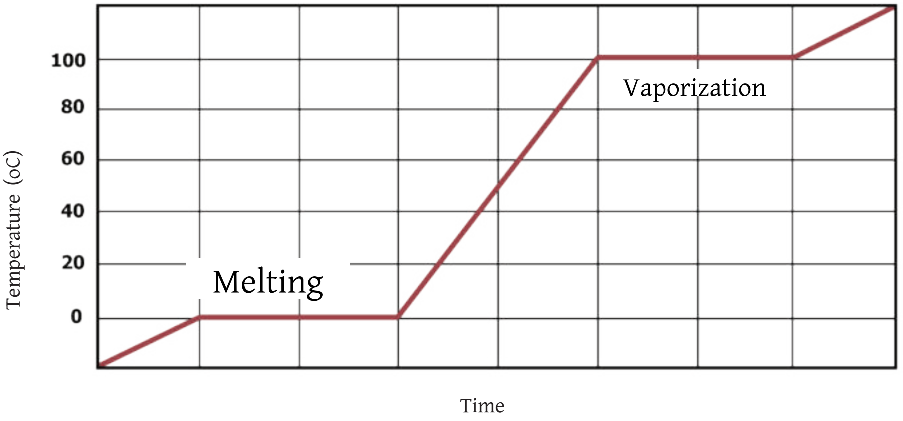


Figure 2.8: Graph of water temperature rise over time. Temperature does not change during melting and evaporation

‘Deposition’ is the opposite process of evaporation where the vapor of a substance is cooled directly into a solid rather than a liquid. Iodine is a precipitate in iodized table salt. Therefore, heating this mixture of iodized table salt easily evaporates the iodine, then the vapor can be cooled to directly convert the iodine vapor into solid iodine.

The amount of expansion or contraction of solid, liquid, and gaseous substances varies by the application or removal of heat.

Change of State of Matter

If ice or wax is melted by heat, they stay at the same temperature during melting. The same happens when other solids are melted and liquefied, only the temperature is different for different substances. You know that the process of conversion from solid to liquid is called 'melting' and this specific temperature of melting is called 'melting point'. The heat given off at this time is used to relax the molecular bonds of the solid molecules and cannot be used to increase their kinetic energy, so the temperature does not rise. Similarly, when water boils, the same thing happens. That is, the temperature remains the same until all the water boils and evaporates. The same thing happens when different liquids are boiled and vaporized, only the temperature is different. The process of converting a liquid into vapor due to the application of heat is called 'evaporation' and the specific temperature at which vaporization takes place is called the 'boiling point' of the substance.

Heat is applied from outside to cause melting or vaporization. Since there is no change in the temperature of the substance during these two events, the entire heat is used to change the state of the substance. The greater the amount of matter, the more heat is required. This amount varies more or less for different substances. This heat used to change the state of matter is called ‘latent heat’. In the case of melting it is known as the 'latent heat of melting' and in the case of evaporation it is known as the 'latent heat of vaporization'.

If the latent heat of a substance is known, we can easily find the heat Q required to change the state of the substance. Because if the mass of the object is m, and the corresponding latent heat of change of state is L, then $Q = mL$

Example: If the latent heat of melting ice is33600 J Kg^{-1} how much heat is required to melt 3 Kg of ice at the melting point to obtain water at 300 K?

Solution: The heat needed to just melt the ice

$Q_1 = m\ L = 3 \times 33600 = 100800$ J

Again, the heat required to raise water at a temperature of 273 K to a temperature of 300 k

$Q_2 = m\ s\ (T_2 - T_1) = 3 \times 4200 \times (300 - 273) = 340200$ J

That is, the total heat required will be $Q_1 + Q_2 = 441000$ J

Since melting and vaporization occur after a certain temperature is reached during heating, you might think that the processes do not occur until that temperature is reached. But that's not true, the boiling point of water is 100 degrees Celsius but we see that if water falls on a floor it dries up at normal room temperature. If we put a little alcohol on the hand and blow it, we feel that place cool. This happens because the alcohol takes its latent heat from our skin to evaporate. This is not difficult to understand if we go back to the molecular model of matter. If a molecule somehow gains enough energy, and because of this, its kinetic energy increases enough, it can come off the surface of a solid or liquid. Since numerous molecules are constantly hitting the surface of a solid or liquid, some of the molecules can be freed from their impact. We have all seen this process.

Just as water takes up its latent heat of vaporization when it evaporates, the reverse is also true; when water vapor condenses into water particles, it returns the latent heat of vaporization as heat. During a cyclone, water rises from the surface of the ocean with the latent heat of evaporation to become water vapor, where the latent heat of evaporation is released as energy when it cools and condenses into water droplets. This energy acts as the mighty force of the cyclone.

2.6 Thermodynamics

The science of conversion of heat energy into other energy is called thermodynamics. Different scientists have thought differently about the origin of heat in the past. Heat was once thought to be caused by the flow of a fluid called caloric, which can neither be created nor destroyed. However, scientist Count Rumford showed through friction with a drill during the piercing of a cannon barrel that heat is not a fluid called caloric, it is a type of mechanical energy. Although there is no caloric theory now, the calorie unit

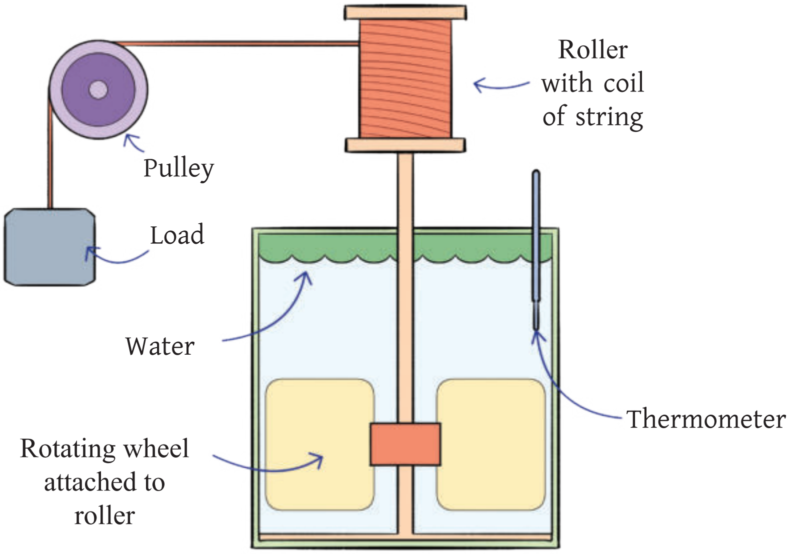


Figure 2.9 Joule's Experiment

still exists, especially a form of this unit is regularly used on various food packages.

Scientist Joule observed a proportional relationship between heat and mechanical work and deduced the mathematical relationship between the two. Scientists then also accepted heat as a form of energy.

Scientist Joule's Experiment

In this chapter, we learned the basic principle of calorimetry and learned to measure heat using temperature and specific heat. In the previous chapter, we learned the mathematical formulas for determining potential energy. By combining these two factors, scientist James Joule performed his famous experiment (Figure 2.9). Here a mass attached to a string wound on a roller through a pulley descends under the influence of gravity. Then the roller rotates and moves a wheel attached to it. The wheel immersed in water stirs and heats the water. The amount of heat generated can be calculated by measuring the change in water temperature with a thermometer. On the other hand, the amount of potential energy converted into work can be calculated from how much the mass has fallen down. Thus Joule discovered the relation of heat to mechanical work.

You know the relative heat of water is 4200 $Jkg^{-1}K^{-1}$ From here Joule was able to raise the temperature by 1K by doing 4200J of work on 1kg of water.

Example: In Joule's experiment, 100 g of water at 310 K is placed inside a closed container. Then what will be the temperature of the water after the agitation caused by dropping a 50 kg mass attached to the roller by a rope 3 m? (Assume no energy is otherwise wasted)

Solution: Here, the potential energy of the mass decreases to $E = mgh = 50 \times 3 \times 9.8 = 1470$ J

If temperature of water after stirring is T_2, then $Q = m\,s\,(T_2 - T_1)$

Since no energy is being wasted in any other way, all of the potential energy lost to the mass will be converted into kinetic energy, and that kinetic energy will heat the water by stirring it.

That is, $E = Q = m\,s\,(T_2 - T_1)$

So, $1470 = 0.1 \times 4200 \times (T_2 - 310)$

Or, $T_2 = 313.5$ K

Later scientists Joule, Clausius, Sadi Carnot and Kelvin advanced thermodynamics, among them Sadi Carnot is called the father of thermodynamics. These scientists rejected the caloric theory of heat as a flowing substance, stating that heat is energy, i.e. the ability to do work.

There are three laws of thermodynamics; these three laws give an idea of how heat energy works. These three laws can be written in different ways, but the main idea of the laws can be expressed very simply by writing like this:

First Law of Thermodynamics: Energy can be converted into heat, internal energy, or work but cannot be created or destroyed.

Second Law of Thermodynamics: When energy is changed from one form to another, some energy is always lost.

Third Law of Thermodynamics: Absolute zero temperature cannot be reached.

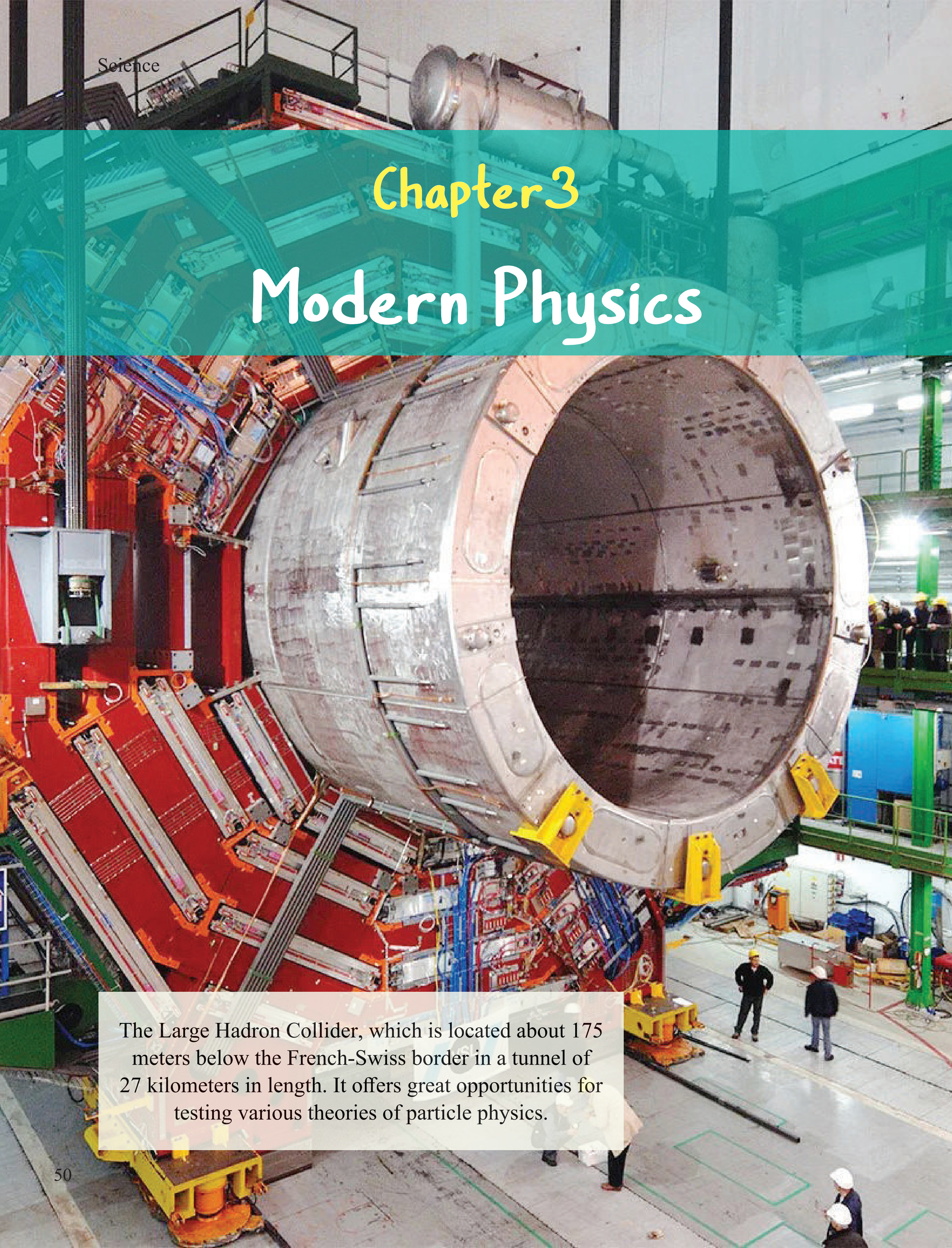
After expressing the three laws of thermodynamics, scientists decided to reveal one more. Because of the importance of the law, it is expressed as the zeroth law of thermodynamics to place it first:

Zeroth Law of Thermodynamics: If two thermodynamic systems are both in thermal equilibrium with a third system, then the two systems are in thermal equilibrium.

Based on this basic formula, we make thermometers.

Chapter 3

Modern Physics



The Large Hadron Collider, which is located about 175 meters below the French-Swiss border in a tunnel of 27 kilometers in length. It offers great opportunities for testing various theories of particle physics.

Chapter 3 Modern Physics

This chapter discusses the following topics:

- ☑ Quantum Mechanics
- ☑ Relativity
- ☑ Particle Physics

3.1 Quantum Mechanics

In the early 20th century, the world's greatest scientists could not find a way to one particular calculation by any means. You have certainly noticed the light radiation from a heated object. If a piece of iron is heated, it turns red, and if it is heated more, it gradually turns blue. Everyone knew that there is a relationship between the intensity of light emitted by a heated object and the wavelength of light. Scientists could explain the intensity of light at short wavelengths correctly with one formula for a heated object, and with another formula for long wavelengths. However, with just one formula, they could not explain the intensity of the radiation of all wavelengths for a heated object.

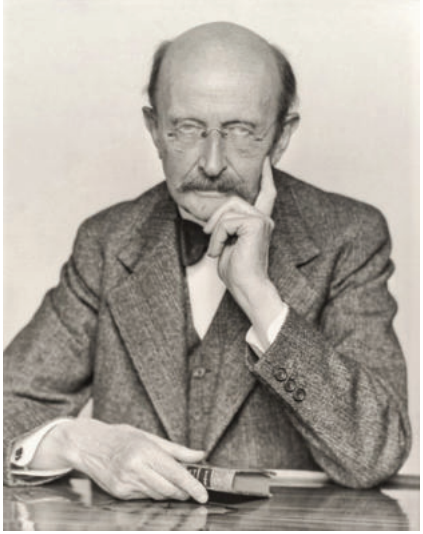


Figure 3.1: Max Planck

Naturally, scientists believed that energy was continuous, but Max Planck (Figure 3.1) thought differently. He considered energy to be discrete, not continuous. That is, he assumed that energy could not be divided into as small parts as desired, and that there was a smallest particle of it. The meaning of low light is a small number of light particles, and the meaning of more light is a large number of light particles. Then, amazingly with one formula, the intensity of energy for light of all wavelengths from small to large for a heated object could be explained. This discrete energy particle is called a quanta of energy, and the new science that was born slowly is called quantum mechanics. Scientists have named the most important and used constant of the universe in the subatomic world after Max Planck, calling it the Planck constant. Its value is 6.634×10^{-34} Js and is expressed as h.

The human eye is sensitive enough, and it is believed that if the human eye were ten times more sensitive, we could see the quanta of light with the naked eye! That is, if you were sitting in a dark room and gradually reducing the intensity of light of a specific wavelength, you would notice that the light does not come continuously, but comes as a discrete emission or particle of light. The intensity of emission of all these particles is the same, but the number of particles of light decreases as the intensity of light decreases.

3.1.1 Wave-particle Duality

We are all familiar with waves. Waves are associated with wavelength, frequency, period, etc., and they carry energy from one place to another. A very important aspect of waves is interference, where one wave combines with another wave to create a wave of greater amplitude, or one wave combines with another wave in reverse to reduce the combined amplitude (Figure 3.2). A very important wave in nature is the

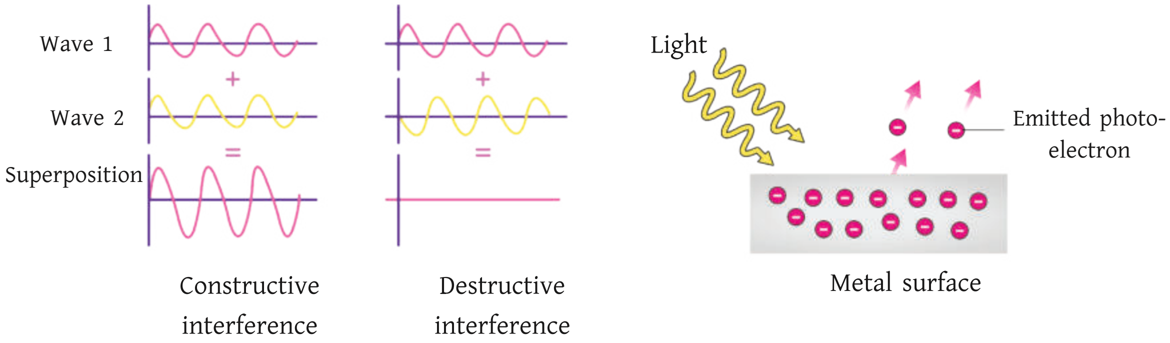


Figure 3.2: (Left) Interference, property of light as wave, and (Right) Photoelectric effect, property of light as particle

electromagnetic wave and a part of this wave, which is caught by the retina of our eye, is what we call light. But surprisingly, in some places, it has been seen that the behavior of light is not like a wave, but like a particle. Light can knock off electrons just as one particle can knock off another particle. One such example of light particles is the photoelectric effect, where light particles or quanta strike a metal and release electrons from it. Einstein won the Nobel Prize for explaining this fascinating phenomenon. You must have seen solar cells which convert sunlight energy into electricity by using this photoelectric effect.

On the other hand, you must also know that electrons are particles; It has mass, it has momentum, it can hit other particles and move them. Interestingly, scientists once discovered to their surprise that sometimes the electron behaves not as a particle, but as a wave! It has a wavelength and amplitude. Not only that, the electron can do interfere like a wave. Electrons behave like waves so precisely that electron microscopes have been designed using this property of electrons.

So, the question is, is light really a wave or a particle? Again, the same question can be asked for electrons. Are electrons actually particles or waves? You may be startled to hear the answer, because the answer is: both! That is, light carries both wave and particle properties. Electrons also have both particle and wave properties. In the case of light, scientists first learned about its wave properties, and in the case of electrons, they first learned about its particle properties, that is the difference. This dual nature may seem strange to you at first, but know that it is indeed possible. Physicists call this phenomenon Wave-particle Duality.

Figure 3.3: Louis De-Broglie

3.1.2 De-Broglie Wavelength

Electrons are not only seen as waves. Scientist de-Broglie (Image 3.3) was the first to state that every substance or particle has a wave, and he even stated the wavelength of that wave. If the momentum of a particle is p then its wavelength λ is:

$$\lambda = h/p$$

where h is Planck's constant. This very simple equation is a surprising equation because on the left side of the equation is the wavelength λ, which is purely a property of the wave, and on the right side is the momentum p, which is purely a property of the particle. This equation combines two completely different properties like waves and particles.

Example: If your mass is 50 kg and you run at 2 m/s, what is your de-Broglie wavelength?

Solution: Your momentum will be $p = 50 \times 2$ kg m/s = 100 kg m/s, so your de-Broglie wavelength will be: $\lambda = (6.634 \times 10^{-34} / 100)$ m $= 6.634 \times 10^{-36}$ m

You see, it is so small that there is no real possibility of seeing it. But if you consider the case of small particles like electron-proton, then its wavelength or wave-like behavior is not such a strange thing.

Example: What is the wavelength of an electron moving at 4×10^{6} ms^{-1}? (Mass of electron is 9.1×10^{-31} kg)

Solution: Wavelength of electron $\lambda = h/p = h/mv$

$$= 6.634 \text{ x } 10^{-34} / (9.1 \text{ x } 10^{-31} \times 4 \text{ x } 10^{6})$$

$$= 1.8 \times 10^{-10} \text{ m}$$

It is reasonable to ask, if indeed there is a wave for all particles, then what is that wave? In very simple terms, this wave is not a real wave, but there is a relationship between this wave and the 'probability' of where a particle can be found.

3.1.3 Heisenberg's Uncertainty Principle

Figure 3.4 shows two different de-Broglie waves associated with a single particle. Now if you are asked in which wavelength of the image is it easy to pinpoint the location of the particle? Of course, you will say in the upper wave. Because the wave is trapped in a small space here, the particle must be there. In the lower wave, because the wave is spread out very far, the position of the object can be anywhere on it, meaning you can no longer tell the position with certainty. If asked now, in which wave of the image can be specified the momentum of the particle? Then you would surely say that the

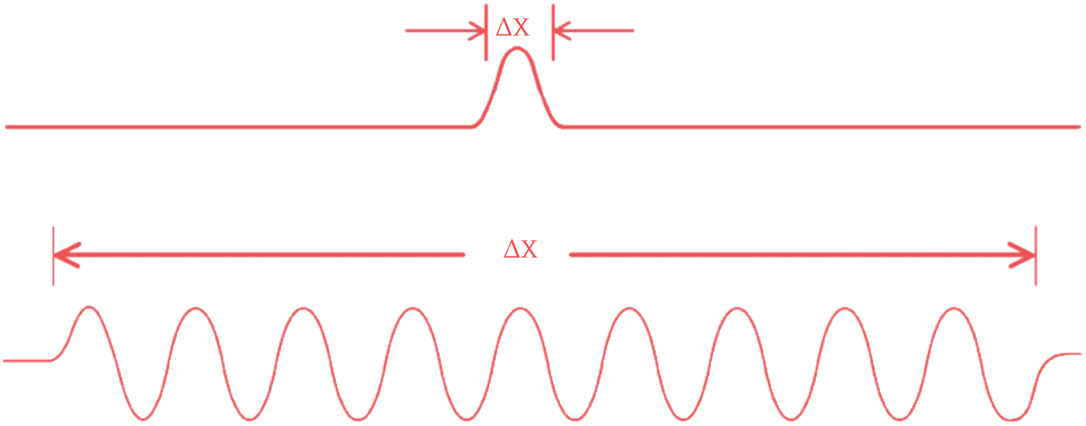


Figure 3.4: Upper wave position uncertainty (Δx) is lower, lower wave position uncertainty (Δx) is higher.

momentum of the lower wave can be specified, because since the wave is so broad, it is possible to extract the wavelength accurately from many wavelengths, and according to de-Broglie's law, the momentum p is h/λ, so the momentum will be measured as accurately as the wavelength λ. That much can be said for sure. The upper wave does not have a whole wavelength—how can its wavelength be estimated? So you can no longer tell the momentum of the particle with certainty in the upper wave.

From this example, you can see that if the position of a particle is known precisely, its momentum becomes uncertain. Again, if the momentum is known well, the position becomes uncertain. This is Heisenberg's (Image 3.5) famous uncertainty formula.

Mathematically, the uncertainty of a position is expressed by Δx. A lower Δx means less uncertainty in position, i.e. the position is well known and a higher Δx means a higher position uncertainty i.e. the position is not well known. Similarly, the momentum uncertainty is expressed as Δp. A lower Δp means less uncertainty in momentum, i.e. we know the momentum better, and a higher Δp means more uncertainty in momentum i.e. we don't know

Figure 3.5: Werner Heisenberg

the momentum well. Using Δx and Δp, Heisenberg's uncertainty formula is written as:

$$\Delta x . \Delta p \geq h/4\pi$$

Remember, not being able to know position and momentum at the same time with certainty is not the inability of scientists or their measuring instruments. It's not that, someday when science is much better, better instruments will be able to measure position and momentum perfectly simultaneously—it never will! Nature has built this uncertainty into its laws. However, since the value of h is very small, the uncertainty value is also very small, so it is never a problem in our daily scientific measurements or technology work.

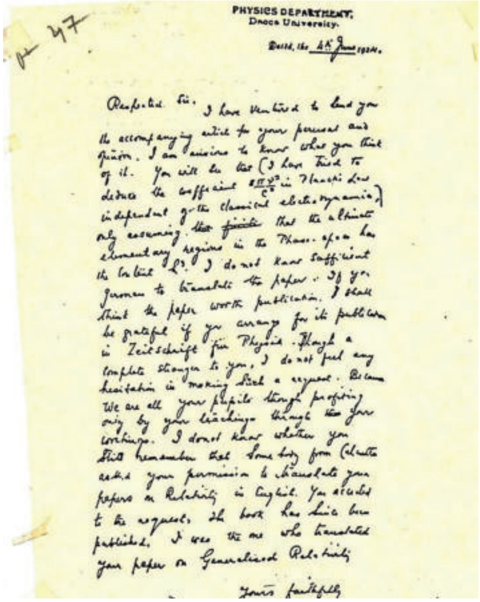
This uncertainty formula has far-reaching implications in physics. Later, those of you who will study physics will see, from this source of uncertainty, that one of the most important branches of science called quantum mechanics has been developed to describe the diverse world of small particles such as electrons, protons, molecules, and atoms!

3.2 Particle Physics

When we look around us, we see people, trees, buildings, and when we look at the sky, we see the moon, the sun, planets, stars, and galaxies in deep space. We all know that everything is made up of some atoms, and those atoms are made up of electrons, protons, and neutrons. You must be curious to know whether these electrons, protons, and neutrons are the fundamental particles or they are made up of something else. What other particles exist besides these three? You have learned that these fundamental particles interact with each other through four types of forces: gravitational force, electromagnetic force, weak nuclear force, and strong nuclear force. But do you know that these forces actually exchange a type of energy particle when they interact? This means that the physical world is created by two types of particles, which are matter particles and energy particles. The branch of science that deals with the division and interaction of matter particles and energy particles is called particle physics. In this chapter, we will introduce you to the extraordinary and diverse world of particle physics. However, to get a real understanding of it, you will need to wait for more advanced studies in physics.

The universe is made up of matter particles and energy particles. Matter particles are called “Fermions” and energy particles are called “Bosons” 1. Therefore, we can say

In 1921, the journey of Bangladesh's first university i.e. Dhaka University began, where Satyendranath Bose was appointed as a teacher in the Department of Physics. In a 1924 letter from Curzon Hall to Einstein, he said that Max Planck's calculation was a bit off, and that it would have been better if the calculations were different. He wrote a paper on how it should be. The young scientist requested Einstein to translate his paper into German and publish it in a journal. Einstein immediately responded to the letter and arranged for Satyen Bose's English article to be translated into German and published in a journal. Because of Satyen Bose's work, half of the particles in the universe are called **Boson** particles after him.



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PHYSICS DEPARTMENT,
Dacca University.
Dated, the 4th June 1924.

Respected Sir, I have ventured to send you
the accompanying article for your perusal and
opinion. I am anxious to know what you think
of it. You will see that (I have tried to
deduce the coefficient $\frac{8\pi\nu^2}{c^3}$ in Planck's Law
independent of the classical electrodynamics)
only assuming ~~that finite~~ that the ultimate
elementary regions in the Phase-space has
the content h^3. I do not know sufficient
German to translate the paper. If you
think the paper worth publication I shall
be grateful if you arrange for its publication
in Zeitschrift für Physik. Though a
complete stranger to you, I do not feel any
hesitation in making such a request. Because
We are all your pupils though profiting
only by your teachings through ~~the~~ your
writings. I do not know whether you
still remember that somebody from Calcutta
asked your permission to translate your
papers on Relativity in English. You acceded
to the request. The book has since been
published. I was the one who translated
your paper on Generalised Relativity.

Yours faithfully

that if any fundamental particle is taken from this universe, it will either be a Fermion or a Boson. The name Boson comes from the name of an Bengali professor Satyen Bose of the Department of Physics at Dhaka University (Image 3.6), and the name Fermion comes from the name of an Italian scientist Enrico Fermi (Image 3.6) 1. Fermions and Bosons have a very important property in common. To put it simply, if particles of the same kind cannot be together, then it is a Fermion. And when particles of the same kind can be together, then it is a Boson. Electrons are Fermions, so when you learned about the structure of atoms,

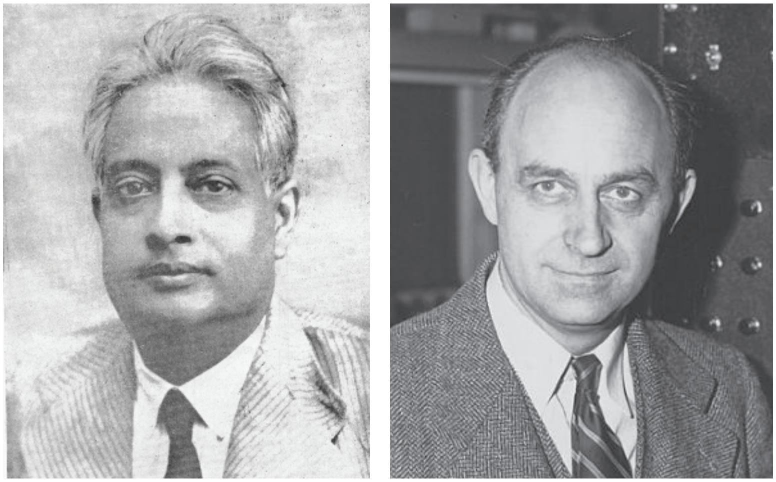


Figure 3.6: Satyen Bose and Enrico Fermi

you noticed that all electrons cannot be kept at one energy level. To accommodate electrons with different properties, they have to move to the next energy level. On the other hand, photons or light particles are Bosons. Photons can exist in one energy level, which is why it is possible to create a laser beam of such intense light.

3.2.1 Atoms are not the Last Word

The entire universe is made up of matter particles fermions and energy particles bosons. Particles called fermions can be further divided into two categories. One part is called quark and the other part is called lepton. Quarks are fermions that experience the strong nuclear force, and those that do not experience the nuclear force are leptons. An electron is a lepton. While studying the structure of atoms, we read about the three basic particles, electrons, protons, and neutrons. Electron is indeed a fundamental particle like lepton, but proton and neutron are not fundamental particles. They are made up of two types of quarks called up quark (u) and down quark (d). We learned that all atoms are made up of electrons, protons, and neutrons. It can now be said more accurately that all atoms are made up of electrons and two types of quarks, up quark and down quark (e and u, d). (Remember that there is nothing above (up) or below (down) these quarks, it is just names given by scientists!)

Quarks come in two types, and leptons also come in two types. One is our familiar electron and the other is called a neutrino. We don’t usually talk about neutrinos in general because it is not visible to the naked eye in any way. Every second, ten lakh neutrinos pass through the iris of your eye, but you will never perceive it. It is almost weightless, it doesn’t easily interact with anything. In fact, it can travel through several light-years long lead without being absorbed! It is another lepton to accompany the electron, so it is called an electron neutrino and is written as νe. We will talk about the energy particles named Bosons a little later, but for now, let’s write a complete list of Fermions. This is very simple:

Fermion		
Quark	u	Up Quark
	d	Down Quark
Lepton	e	Electron
	ν_e	Electron Neutrino

Another very important thing to be told at this time is that every particle has an antiparticle. When a particle and antiparticle come together, both disappear and are converted into energy. Not only that, energy can be used to create particles and their antiparticles in a suitable environment. This universe was supposed to have an equal amount of particles and their antiparticles. But scientists still don't know why the universe is made of only particles. But to complete the above list, we must add their antiparticles to this family of fermions. So the list will be like this:

Fermion		
	Matter	Anti-matter
Quark	u	$\bar{u}$
	d	$\bar{d}$
Lepton	e	$\bar{e}$
	ν_e	$\bar{\nu}_e$

The above particles are matter particles, we have to add energy particle bosons to the list to exchange force or energy in them. They are:

Boson		
Eletro-magnetic Force	γ	Photon
Weak Nuclear Force	Z_0, W^+, W^-	G not, W plus and W minus
Strong Nuclear Force	g	Gluon
Gravitational Force	G	Graviton

You see here the photon or particle of light as we know it is responsible for the electromagnetic force. Z not (Z_0) and W plus and W minus (W^+, W^-) are carriers of weak nuclear force, gluon (g) is the carrier of strong nuclear force and graviton (G) is the carrier of gravitational force. It should be noted here that the existence of other particles in this list has been confirmed through experiments, but the existence of gravitons has not yet been discovered.

3.2.2 Standard Model

So one would be quite happy to think that it is possible to explain the composition of all matter in this universe with only four matter fermions. But actually the matter is not so simple in the end. It turns out that the family of fermions mentioned is not enough for various reasons. We need two more families like this. The family of u, d, e, ν_e is called the first generation. Although everything in the universe is formed by this first generation, we need two more such generations to understand the mysteries of nature: c, s, μ, ν_μ and t, b, τ, ν_τ

Second Generation		
Quark	c	Charm Quark
	s	Strange Quark
Lepton	μ	Muon
	ν_μ	Muon Neutrino

Third Generation		
Quark	t	Top Quark
	b	Bottom Quark
Lepton	τ	Tauon
	ν_τ	Tauon Neutrino

And although not written separately, it must be remembered that each of them has its antiparticle. If we do not write the antimatter separately, all the elementary particles in the universe can be written in a small table (Figure 3.7). For coherent reasons, you might think that of energy particles should also be included in our list. But the interesting thing is that some of these energy particles, which exchange force or energy within the matter particles, are antiparticles of themselves, some are antiparticles of each other, so there is no need to list them separately.

The model of physics that explains nature using these particles is called the Standard Model. You may know about the periodic table. Just as the elements are arranged in sequence in the periodic table, so in the Standard Model the elements are arranged in sequence in a table. But you have to remember that these particles have mass, charge, and many other properties, which are not mentioned here to keep the discussion simple.

At one time, atoms were thought of as indivisible units. Later, with the discovery of the electron and the atomic nucleus, that idea changed. After the discovery of the neutron nearly ninety years ago, some physicists thought that all particles in particle physics were known. In the years since, hundreds of physicists have broken down the particle ladder and gone deeper. Some have theorized the behavior of these particles, and some have discovered the existence of new particles in the laboratory.

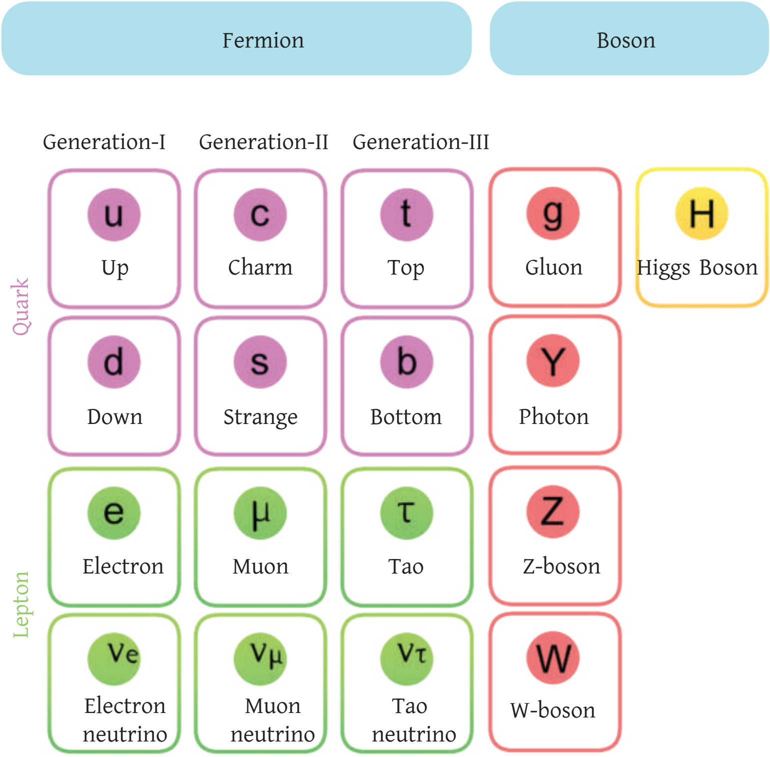


Figure 3.7: Standard Model of Basic Particles

In order to determine the mass of the particles that have been discussed so far, physicists had already assumed the existence of another force called the Higgs Boson (H). Finally, in 2013, scientists at a laboratory called CERN confirmed its existence—which is now listed in the Standard Model (Figure 3.7). The discovery of the Higgs boson was a major achievement in theoretical physics.

3.3 Theory of Relativity

Einstein's (Image 3.8) famous theory of relativity was built on the following two postulates:

(1) The laws of physics will appear the same in all inertial reference frames, and
(2) The speed of light will be the same in all inertial reference frames

To those of you reading these two postulates, the first postulate may seem fairly acceptable. There is no such thing as a perfectly fixed reference frame, for all reference frames the relative velocities of the two structures must be determined by comparing

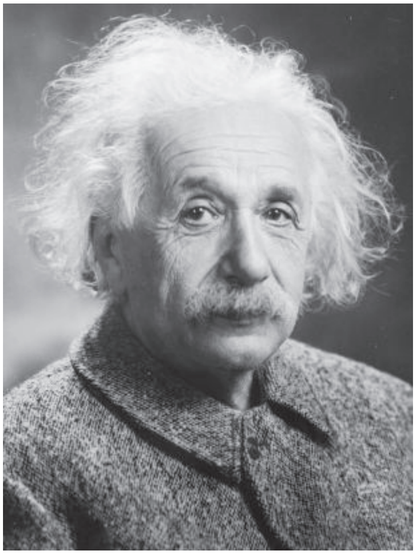


Figure 3.8: Albert Einstein

one with the other. The earth itself is moving around the sun at a speed of about 100,000 kilometers per hour. So no inert reference frame is really a special structure, they are all the same. So there is no scope for different physics in different reference frames. But the second postulate does not correspond to our daily experience. If a car is traveling at 60 km/h and you are traveling at 40 km/h, you will feel that the other car is traveling at 60 - 40 = 20 km/h relative to you. But the second postulate says otherwise. We know that if someone sends a beam of light at you with a flashlight, you will feel that the beam is reaching you at the speed of light. Now if you yourself are traveling at half the speed of light, then if you turn on the flashlight again and send the light beam towards you, the light will also reach you at half the speed, but the second postulate says that the light will still reach you at the speed of light!

However, here are a few examples of what strange things happen when two of the accepted principles of relativity are used.

3.3.1 Time Dilation

Suppose you are standing at the station and your friend is sitting on the train, which has speed v, two mirrors near your friend are one below the other at height H; Light is reflected up from the lower mirror and down from the upper mirror (Fig. 3.9). When the light goes from bottom to top (or top to bottom) it takes time t_0 and the clock clicks. This clock is your friend's clock. Then, $t_o = H/c$ where c is the speed of light. You also decide you will stand at the station and look inside the moving train and measure the clicks. Since the train is moving at speed v, you must see that the upper mirror has moved a distance vt at the time t when the first click of 'your' watch occurred, and a further distance vt at the time of the second click. So you would think that the distance traveled by the light during the ticking of the clock according to the Pythagorean formula is:

$$\sqrt{H^2 + v^2t^2}$$

Again, Einstein said that the speed of light is the same everywhere, so if we call the time of one click of your t, then,

$$t = \frac{\sqrt{H^2 + v^2t^2}}{c}$$

That is, $$t^2 = \frac{H^2}{c^2} + \frac{v^2t^2}{c^2}$$

But we know, the click of your friend's clock $t_o = H/c$, That is, $H^2/c^2 = t_o^2$

Then we can write, $t^2 = t_o^2 + v^2t^2/c^2$

or, $t^2 (1 - v^2/c^2) = t_o^2$

or, $t^2 = t_o^2 / (1 - v^2/c^2)$

That is, $$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This simple equation has completely turned the world we know upside down. Let us remind you again, here t is the time measured by your watch, and t_o is the time measured by your friend's watch. You are standing still and your friend v is moving, that is the difference.

Here, there is not much difference between t and t_o when the value of v is small, but something completely different happens if the value

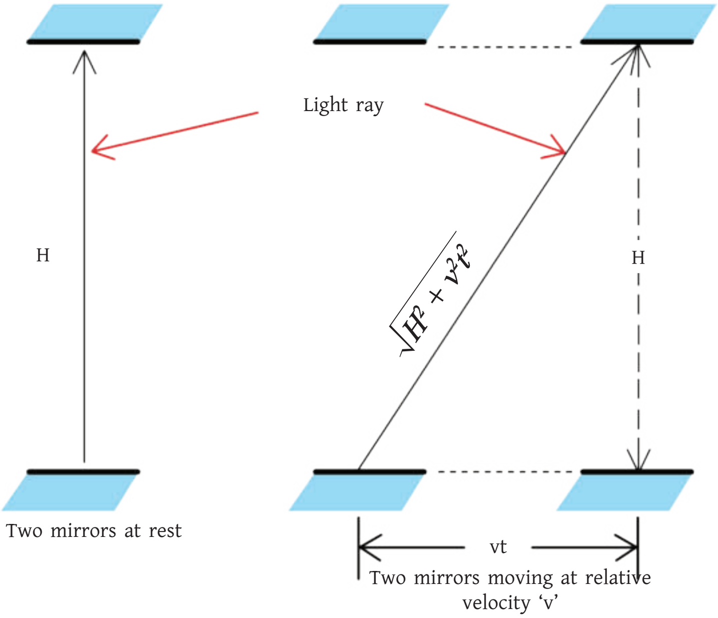


Figure 3.9: Light rays transmitted through (a) Fixed and (b) a moving mirror

of v is close to the speed of light. For example if v = 0.99c then

$$t = \frac{t_0}{\sqrt{1 - 0.99^2}} = 7t_0$$

That is, if your friend spends ten years on a train moving at 0.99c (t_o = 10 years) then his age will increase by exactly ten years. But, at the same time your age will increase (t = 7 and t_o = 70) seventy years! Leaving in fifteen years, he will come back as a young man of twenty-five years and see that you have started in fifteen years and within this time have grown eighty-five years old!

Your friend is moving with velocity v relative to you, but you are also moving with velocity v relative to your friend. So why is the opposite not true? That is, why don't you spend ten years discovering that your friend has aged seventy years while you have aged ten years?

Your friend is moving with velocity v relative to you, but you are also moving with velocity v relative to your friend. So why is the opposite not true? That is, why don't you spend ten years discovering that your friend has aged seventy years while you have aged ten years?

This is a very interesting question in relativity. You and your friend have to meet to see who is older, unless you meet you will never know who is older. In order to meet, one has to stop and change speed, and come back. One who stops and changes speed will have less time elapsed. Why that would be the case is not too difficult to explain, but for now we leave it to be discused in higher grade.

This famous equation of time dilation

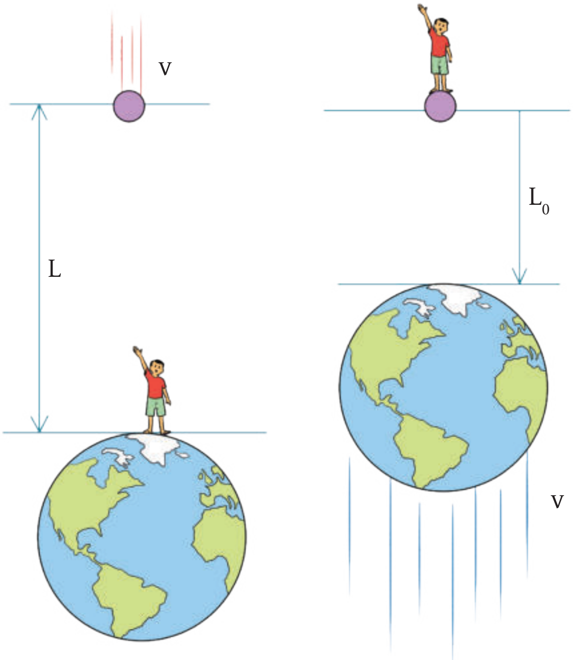


Figure 3.10: A muon rushing from a stationary Earth will appear to be rushing down with velocity v. From the muon it would appear that the Earth is moving towards the muon with velocity v.

could have been just a fun formula but it isn't. Scientists have seen numerous examples of this and it is true.

3.3.2 Space Contraction

You read about muons as second-generation leptons in the previous chapter. These muon particles are produced by cosmic rays about 10 km above the Earth's surface in the atmosphere and have a lifetime of only 2.2 microseconds. Even if it were to travel at about the speed of light (3 x 10^8 m/s), it would only travel a distance of 0.66 km in this time, never reaching Earth's surface.

But we regularly see muons on the surface of the Earth because time dilation occurs as they travel at speeds close to the speed of light (0.998c). 2.2 Microsecond time dilation causes its value to be:

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{2.2}{\sqrt{1-0.998^2}} = \frac{2.2}{\sqrt{0.004}} = \frac{2.2}{0.063} = 35\mu s$$

A distance of 10.5 km is covered in 35 microseconds at a speed of 0.998c, which is enough to reach the Earth's surface.

The arrival of the muon to the Earth's surface can also be explained in another way. Let's say that the Earth's surface is at a distance L from the top of the atmosphere and you have watched a muon cross this distance at time t (Figure 3.10). So, to you it would seem like the muon's velocity is

$$v = L/t$$

Again in the muon clock (!) the muon will appear to be standing still, the Earth is moving towards it with velocity v (Fig. 3.10) and the Earth has reached it at time t_0. If the Earth appears to muon to be at a distance L_0, its velocity v is:

$$v = L_0/t_0$$

The two velocities are equal, so we can write:

$$L/t = L_0/t_0$$

$$\text{or,}\quad (t_0/t) = (L_0/L)$$

$$\text{or,} \quad L_0 = L(t_0/t)$$

But, we know $t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$$\text{or,} \quad \frac{t_0}{t} = \sqrt{1 - \frac{v^2}{c^2}}$$

So by substituting the value of (t_0/t) into the equation $L_0 = L(t_0/t)$ we get:

$$L_0 = L\sqrt{1 - \frac{v^2}{c^2}}$$

Note that the value of $\sqrt{1 - \frac{v^2}{c^2}}$ -is always less than 1, so the value of L_0 is always less than L. Here if something has a length L (10.5km for muon) relative to us at rest then the distance from the structure moving with velocity v relative to us will appear to be L_0 (0.63km for muon). So when the muon is rushing towards the earth, it seems that it is stationary, but the earth is rushing towards it, because of this, the entire distance from the atmosphere to the earth has become smaller. So the muon has traveled this short distance with only 2.2 microseconds to live!

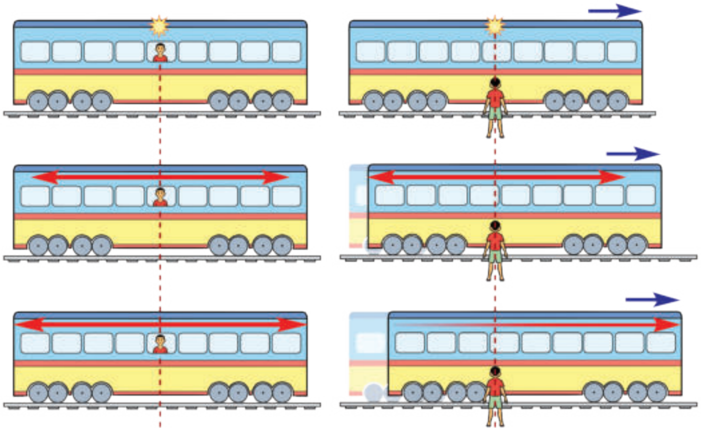


Figure 3.11: (left) If a person sitting in the middle of a moving train emits two light rays simultaneously on either side, he will see that both light rays reach the end of the train simultaneously. (Right) A person standing outside and looking at a moving train will see that as the train moves to the right, the light beam reaches the end of the train first on the left, and later on the right.

3.3.3 Relative Momentum and Energy

We all know that we need three coordinates for three dimensions to specify the position of an object in our three-dimensional world, and in a coordinate system the coordinates of those three dimensions are usually expressed as x, y and z. Now get ready for a surprising fact: Einstein showed in his theory of relativity that nature can be explained much more easily if we think of the three-dimensional world as a four-dimensional world, with the fourth dimension being time. In this four-dimensional world, an object's position is not only specified by three coordinates, but time is also used as a dimension. Later you will have the opportunity to learn how this new understanding not only explained the world of science differently, but also gave birth to many new sciences. For now, we only present you with a few new observations, so imagine a fixed frame and another frame associated with an object in motion relative to it.

1. Two events that are simultaneous in one inertial reference frame are not simultaneous in a different dynamic reference frame. (Figure 3.11)

2. Two events that occur at the same place but at different times in one inertial reference frame, it would appear to occur in different places in a different dynamic reference frame.

As you can see, relativity theory has completely changed our previous concept of time.

But the most important formula in the world of relativity, as you have been told many times before, is:

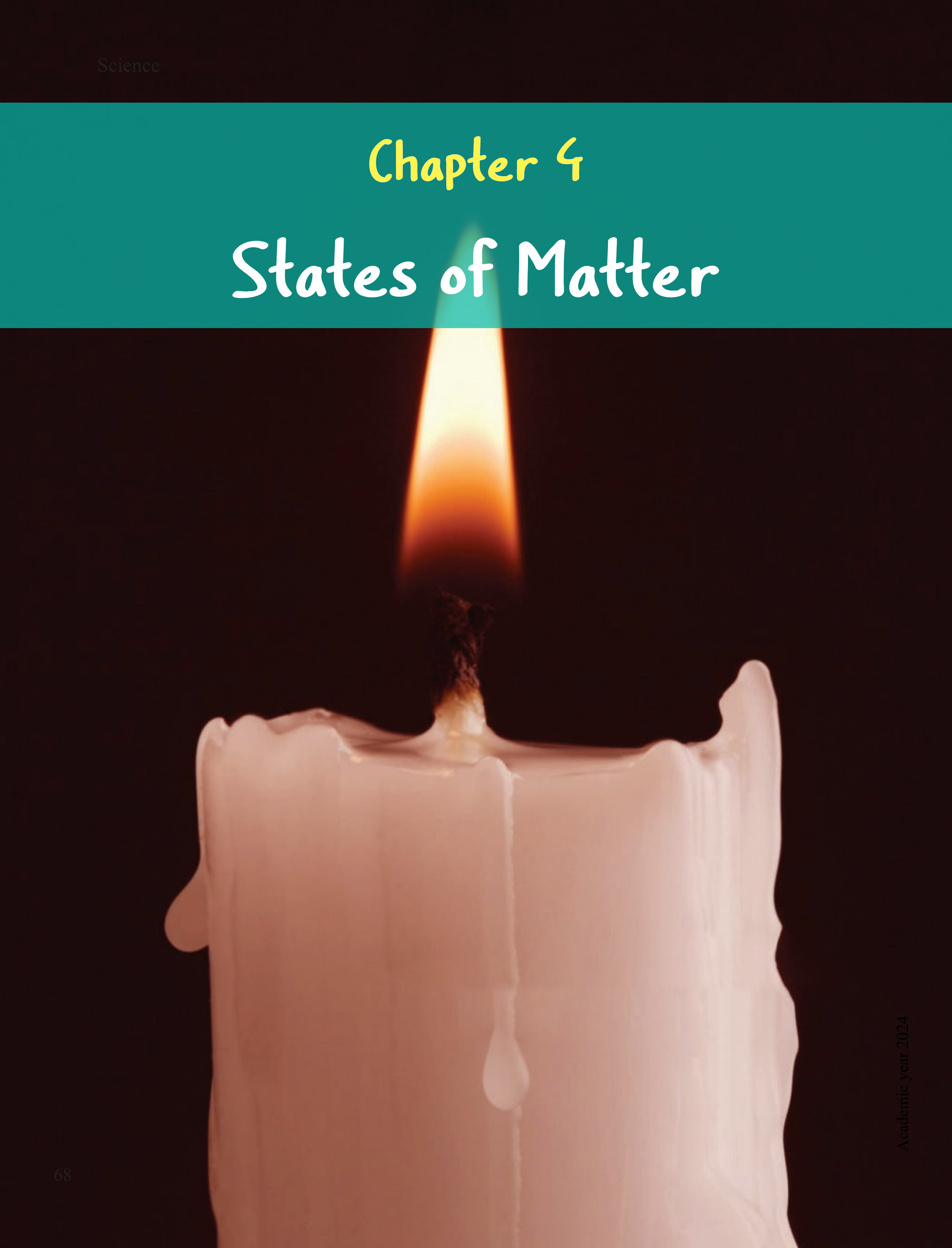
$$E = mc^2$$

Here E is energy, m is mass, and c is the value of the speed of light. That is, even the mass of matter can actually be converted into energy. In that case, a large amount of energy can be generated from a small amount of mass. This formula can be extracted by going a little deeper into the theory of relativity, but we will not do that for now, just giving you the formula!

In this discussion of the theory of relativity, we have always assumed momentum, considering a special state without considering any acceleration. That is why it is called the special theory of relativity. When acceleration is considered instead of momentum, it is the general theory of relativity. General relativity explains everything from the Big Bang, the expansion of the universe, or the existence of black holes.

Chapter 4

States of Matter



Chapter 4

States of Matter

The following topics are discussed in this chapter: :

☑ Three states of matter
☑ Kinetic theory of particles
☑ Diffusion, effusion
☑ Candle burning and three states of wax
☑ Melting and evaporation, distillation and sublimation

Solid, liquid, and gaseous- the nature and characteristics differ in these three states of matter. So, their use is also different in the three states. The nature and characteristics of different states of matter in terms of different states and various issues related to daily life are discussed in this chapter.

4.1 Kinetic Theory of Particles

We know that all types of matter are composed of tiny particles (atoms and molecules). The kinetic energy of these particles is controlled by temperature and affects the state of the matter (solid, liquid, or gaseous). These particles of matter attract each other and, therefore, there is a type of interparticle force of attraction (intermolecular or interatomic) among them. The solid, liquid and gaseous states of matter can be explained by the kinetic energy of the particles and the interparticle force of attraction and this theory of explanation is called the kinetic theory of particles.

The force of attraction among the particles of solids is very strong. As a result, the particles remain very close to each other or are in close contact, and they cannot move from their position. When heat is applied to a solid, the particles absorb heat energy and vibrate. When more heat is applied, the particles vibrate so much that they free themselves a little from the interparticle forces of attraction and gain some kinetic energy. This state of matter is known as the liquid state. We know that a liquid has a definite volume but no

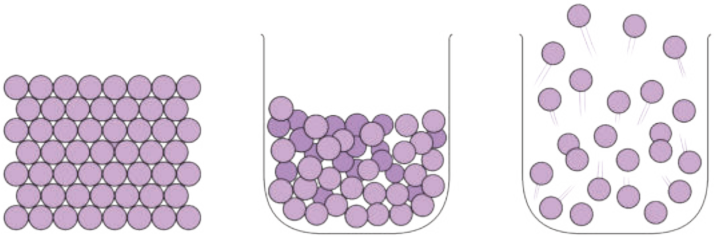


Figure 4.1: Solids, Liquids and Gases

definite shape. In this state, if more heat is applied to a liquid, the particles absorb heat energy and increase their kinetic energy, and at one time the kinetic energy increases so much that the particles are almost free from the force of attraction among them and start moving randomly. In this state, the liquid turns into a gaseous state (Figure 4.1). We know that in the gaseous state, a substance doesn't have a definite volume. Rather, the particles of the substance move around within the volume of the container in which they are placed. When substances are in the gaseous state, and more heat is applied, the particles will move around even faster, and their kinetic energy will increase.

4.2 Diffusion

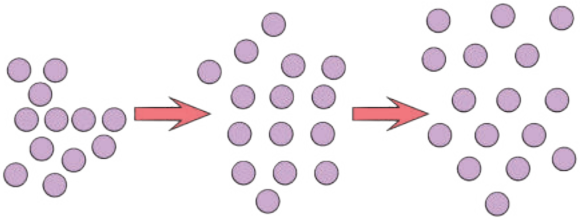


Figure 4.2: The Process of Diffusion of Gases

If a substance is at a high concentration, the particles of that substance, tend to move towards the lower concentration. This process of the particles of a solid, liquid, or gaseous substance spreading out spontaneously and evenly from a region of high concentration to a region of low concentration is called diffusion (Figure 4.2). For the process of diffusion to occur, there must be a difference in the concentration of the substance. As an example of the diffusion process, we can talk about the open bottle of perfume. If we keep an open bottle of perfume in one corner of the room, its fragrance spreads around the room within a few minutes. This process of spreading happens through diffusion. If it takes less time for the fragrance to spread, we say that its diffusion rate is high. Again, if it takes more time to spread, then its diffusion rate is low. The rate of diffusion also depends on the size and mass of the particles. Small particles can spread faster than large particles. So, the diffusion rate of small particles is higher than that of large particles.

Diffusion Process of Solids:

you take a cup of hot water and put a tea bag in it, you will observe that over time, the dark red tea extract or liquor coming out of the teabag slowly spreading into the water in the cup. (Figure 4.3) After a while, when you take the teabag out of the cup, you will find that the entire water in the cup has turned dark-red, that is, the colour of the tea leaves in the teabag has spread throughout the water in the cup through the process of diffusion. Due to the use of hot water in the cup, the diffusion rate is high. If you use cold water in the cup and dip the tea bag in it, you will see that the liqueur spreads much slower. In the case of hot water, the particles of the tea extract gain more kinetic energy by absorbing heat from the water and spread quickly, while in lower temperatures, this process occurs at a much slower pace.

Figure 4.3: Diffusion of tea extract in water

Figure 4.4 : Diffusion of blue solution in water

Diffusion Process of Liquids:

If you take a glass or any clean container with some water and add a drop or two of blue food colouring, you will see the blue colour spreading in the water in the glass (Figure 4.4). Gradually, the colour of the entire water will turn blue. That is, the particles of blue food colouring will spread throughout the water in the beaker or container through diffusion. The process will be slow in cold water, but it will happen very quickly in hot water.

Diffusion of Two Gaseous Substances:

It has been

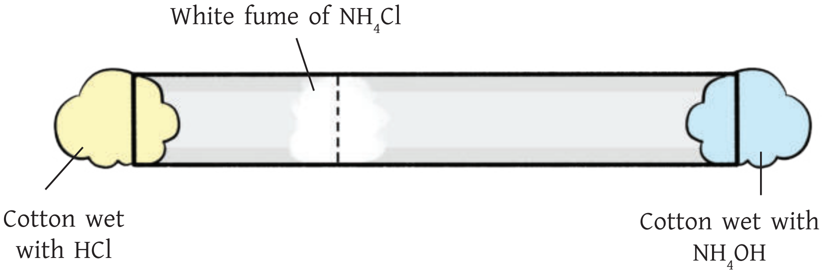


Figure 4.5: Diffusion of two gases (HCl and NH_3).

mentioned that if the particles of a gas are small, the diffusion rate is higher. This is demonstrated through a typical laboratory experiment in a controlled and safe environment (Figure 4.5). A long glass tube with two open ends is taken for this experiment. Then, a piece of cotton is soaked in a concentrated hydrochloric acid (HCl) solution and placed at one end of the long glass tube as illustrated in the figure. Another piece of cotton soaked in ammonium hydroxide (NH_4OH) solution is placed at the other end of the tube. Then HCl gas will be released from the cotton soaked in HCl solution and NH_3 gas will be released from the cotton soaked in NH_4OH solution and they will start spreading inside the glass tube.

After a while, HCl gas and NH_3 gas will react with each other and start producing Ammonium Chloride (NH_4Cl), which will be visible as white fumes inside the glass tube. However, it will be observed that the white fumes are not exactly in the middle of the glass tube. It is away from the cotton soaked in NH_4OH solution and closer to the cotton soaked in HCl solution. From this, it can be clearly understood that NH_3 gas has rapidly diffused a greater distance compared to HCl gas. The molecular mass of NH_3 gas is 17 and the molecular mass of HCl gas is 36.5. So, the diffusion rate of NH_3 gas is greater than that of HCl gas and this gas has travelled a greater distance.

4.3 Effusion

Effusion is a process in which a gas confined in a container escapes with force through a narrow hole in the container, from a high-pressure area inside the container to a low-pressure area outside the container (Figure 4.6). Such a narrow hole is often called a pinhole. The reason why gas escapes from the container in this way is due to the difference in pressure between the inside and outside of the container. During diffusion, it occurs due to a difference in gas concentration but during effusion, it occurs due to gas pressure. In other words, there is no effect of pressure in the case of diffusion, but

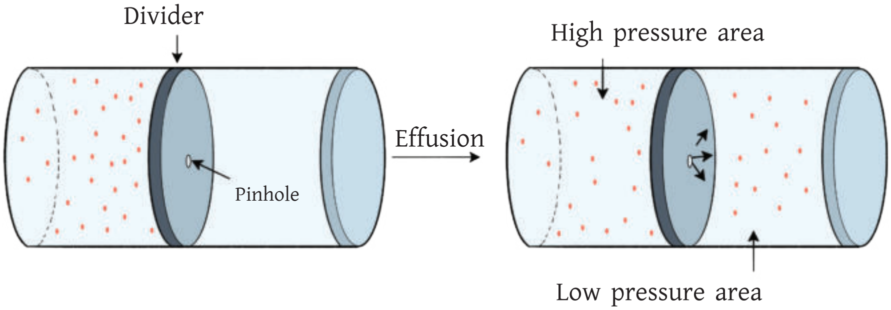


Figure 4.6: The effusion process

there is an effect of pressure in the case of effusion. Another significant difference is that, in diffusion, solid, liquid or gaseous substances spread throughout the suitable medium, but in diffusion, only gaseous substances escape through narrow holes in the gaseous medium at high speed.

Now, let's give some examples of effusion. If a small leak is made in an inflated balloon, the high-pressure air inside the balloon will quickly escape through the leak. Attempting to make a leak an inflated balloon causes the balloon to burst since the stretched balloon moves too quickly around the leak and enlarges the leak. If you put a piece of scotch tape where you want to make the leak and then pierce it with a pin, the balloon will not burst. Then, air will continue to escape from the balloon through the leak, and the balloon will slowly deflate. As the air pressure inside the balloon is greater than the air pressure outside the balloon due to high-pressure leakage, the air in the balloon moves towards the lower pressure as soon as the leak is done, and this process is effusion.

In our daily lives, we can see more examples of effusion. For example, we use Compressed Natural Gas (CNG) as fuel in various vehicles. CNG is basically methane (CH_4) gas compressed under high pressure. In this case, while the vehicle is driven, methane gas is released from the CNG cylinder and enters the engine of the vehicle. Again, at home, we often use gas stored in cylinders as fuel for cooking. In this case, propane (C_3H_8) and butane (C_4H_{10}) gases are compressed at high pressure and stored in liquid form in cylinders. When the gas stove is lit, if the mouth of the cylinder is opened, it turns into gas and comes out at high speed. That is, effusion occurs in this case too.

4.4 Distillation and Sublimation

4.4.1 Distillation:

You know that the process of converting a liquid substance into vapour by applying heat is called evaporation. You all must have seen the water evaporate while heating the water in the kettle. On the other hand, when we cool down the vapour, it condenses into a liquid, which we call condensation. We see small droplets of water on a chilled soft drink bottle. Here the water vapour releases its heat energy and cools down into water particles. This is an example of condensation.

On the other hand, distillation is the process of transforming a liquid into vapour by heating and then condensing it back to liquid through cooling (Figure 4.7). Therefore,

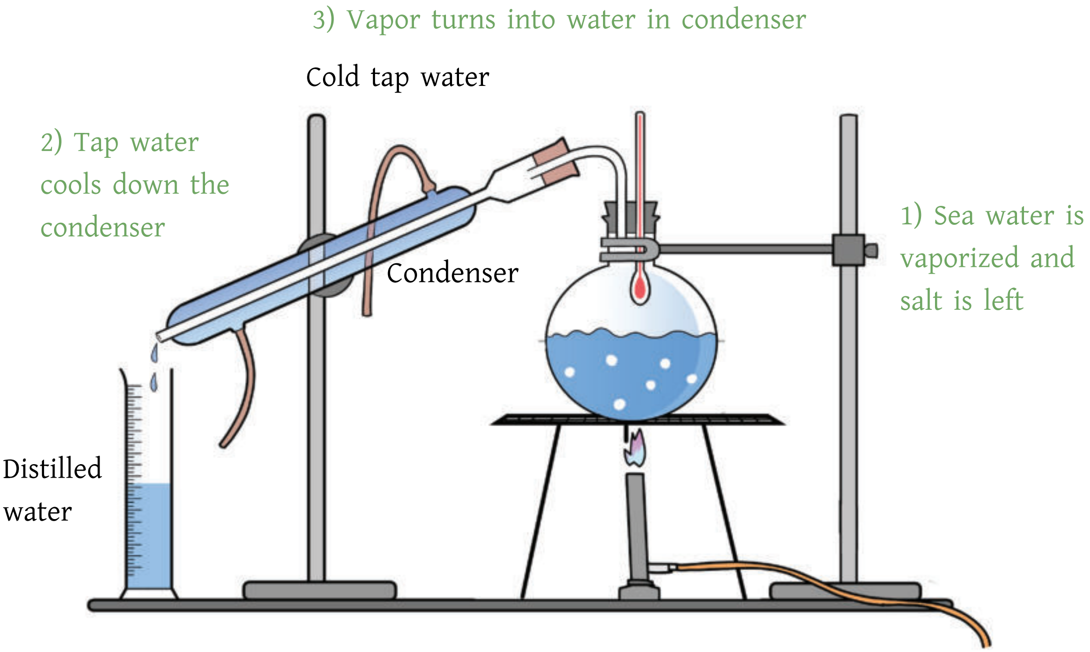


Figure 4.7: Distillation experiment in laboratory

distillation can be expressed as:

Distillation = Vaporization + Condensation

It is important to note that no chemical reaction occurs during the distillation process. When there are multiple substances in a mixture, distillation is used to obtain pure components from the mixture. Therefore, it is a method of separating a component from a mixture.

The experiment of distillation can be done using appropriate containers in a safe laboratory environment. For example, if impurities are mixed with water, pure water can be separated by distillation. Distillation is also widely used in chemical industry factories. For example, crude oil extracted from oil mines is refined through the distillation process (Figure 4.8). Not only that, different substances are separated from crude oil at different temperatures. This process is called fractional distillation.

4.4.2 Sublimation:

Sublimation is a process in which heat is applied to a solid and, as a result, the solid turns directly into vapour rather than a liquid. You may have heard or seen naphthalene. It is used to protect clothes from insects. When naphthalene is heated, it does not first become liquid but directly becomes a gaseous substance. Dry ice is a solid form of frozen carbon dioxide. In its gaseous or vapour state, dry ice is more stable than its solid form. When it comes in contact with air, it changes directly from a solid state to a gaseous state. This is also another example of sublimation.

In addition, substances such as Ammonium Chloride (NH_4Cl), Camphor ($C_{10}H_{16}O$), Iodine (I_2), and Aluminium Chloride ($AlCl_3$), when heated, directly turns into vapour without first becoming liquid. These substances are called sublimated substances.

The sublimation process can be easily observed by conducting the following simple experiment in the appropriate safe environment of the laboratory (Figure 4.9). A certain amount of Ammonium Chloride (NH_4Cl) is taken in a beaker and the open mouth of the beaker is covered with a glass lid. Then, some ice cubes are placed on top of the glass lid so that the vaporized ammonium chloride can cool down and accumulate beneath

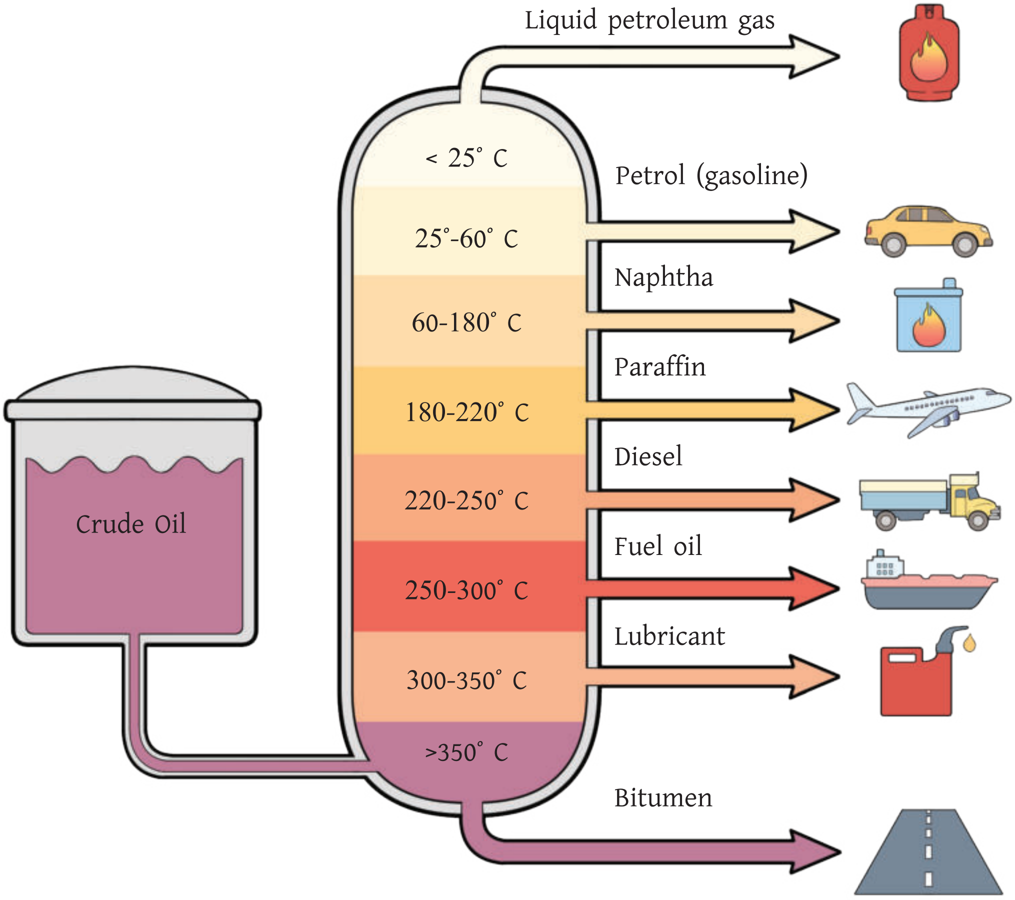
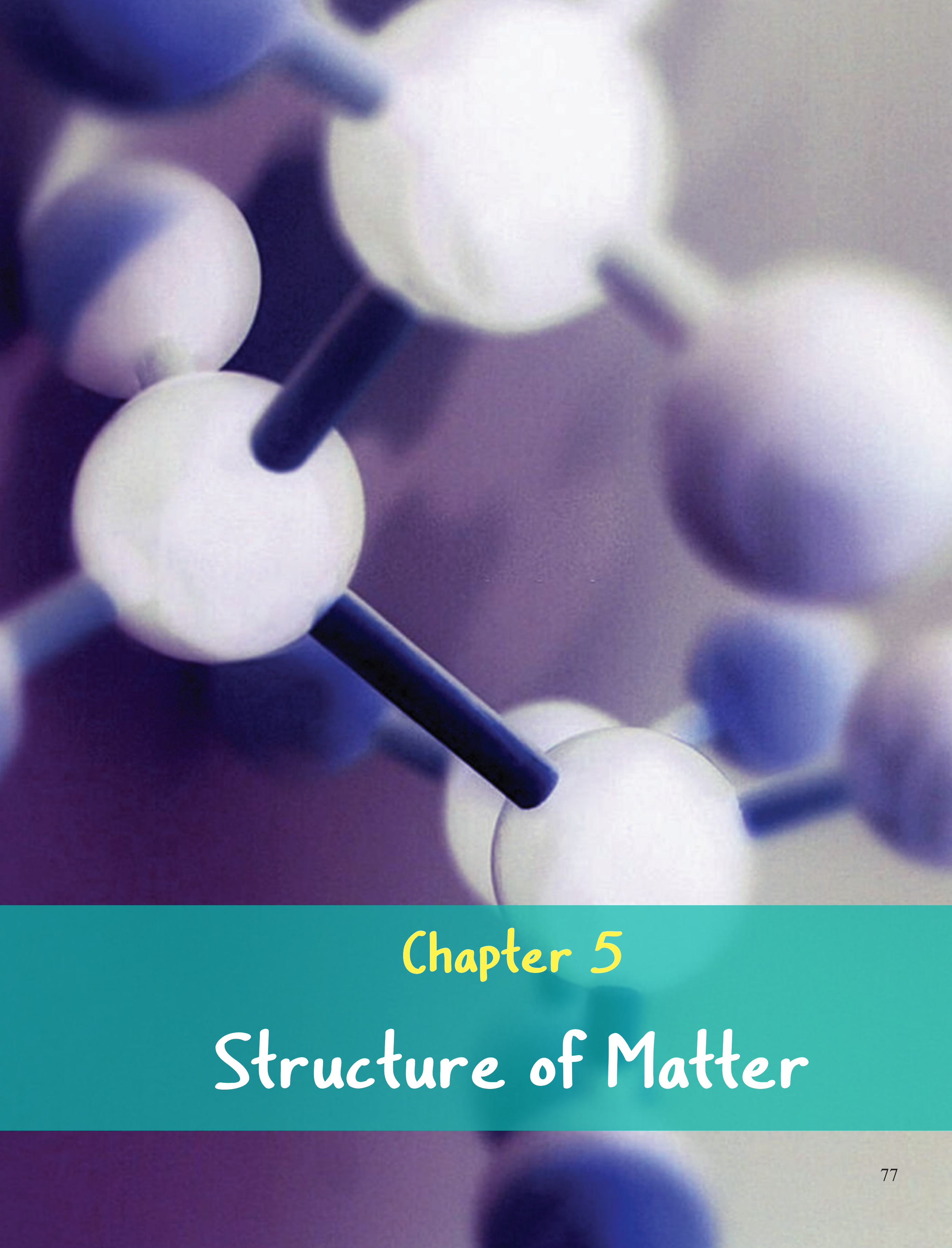


Figure 4.8: Extraction of various substances by partial distillation in an oil refinery.

the lid. Now, if heat is applied to the beaker, it can be seen that the solid ammonium chloride is turning into a gaseous state. This vaporized or gaseous ammonium chloride rises to the glass lid, cools down on the glass lid, and accumulates as solid Ammonium Chloride beneath the lid.

If a sublimated substance is mixed in a mixture of solid substances, then that sublimated substance can be easily separated from the mixture. For example, if ammonium chloride (NH_4Cl) is mixed with table salt ($NaCl$), these substances can be separated easily through the process of sublimation. Again, iodine can be separated from iodized table salt through sublimation. We already know that if heat is applied to a sublimated substance in the solid state, it easily becomes vapourized or gaseous. Therefore, when heat is applied to iodized table salt, iodine will easily evaporate. Again, if that vapor is cooled, it will turn into solid iodine.



Chapter 5

Structure of Matter

Chapter 5

Structure of Matter

In this chapter, the following topics are discussed:

☑ Particles of an Atom, Rutherford's Atomic Model, Bohr's Atomic Model

☑ Arrangement of Electrons in the Energy Levels of Atom

☑ Atomic Mass or Relative Atomic Mass

☑ Determining the Relative Atomic Mass of a Molecule from the Isotopic Abundance Percentage

☑ Determining the Relative Molecular Mass from the Relative Atomic Mass of an Element

5.1 Particles of an Atom

In the previous class, you've learned about the structure of an atom. You know that atoms are primarily composed of three particles: electrons, protons, and neutrons. In the center of the atom is the nucleus, which contains protons and neutrons. Electrons orbit the nucleus, revolving around it. Following are some information about electrons, protons, and neutrons:

Electron

An electron is a fundamental particle of an atom with a negative charge. Its charge is -1.602×10^{-19} coulombs. J. J. Thomson is credited with the discovery of the electron, as he accurately determined its mass and charge for the first time. Below are some additional characteristics of electrons:

1. The mass of an electron is 9.109×10^{-31} kg, which is approximately 1837 times less than the mass of a proton. Therefore, neglecting the relative mass of electrons compared to neutrons and protons does not result in significant loss or error.

2. 2. Electrons are assigned a relative charge of -1. Electrons are often denoted by the symbol 'e'.

Proton

A proton is a positively charged fundamental particle of an atom. It carries a charge equal to $+1.602 \times 10^{-19}$ coulombs. The discovery of the proton is credited to Ernest Rutherford. Here are some additional characteristics of protons:

1. The mass of a proton is 1.673×10^{-27} kg.
2. Protons can be obtained through the emission of the single electron from a hydrogen atom.
3. Protons have a relative charge of +1 and a relative mass of +1. They are commonly denoted by the symbol 'p'.

Neutron

James Chadwick discovered the neutron in 1932. Neutrons have no charge and are present in the nucleus of all atoms except hydrogen. Here are some additional important points about neutrons:

1. The difference in the number of neutrons in the nuclei of two different isotopes of an element contributes to the difference in their masses.
2. The mass of a neutron is approximately 1.675×10^{-27} kg, slightly greater than the mass of a proton.
3. Neutrons have a relative charge of 0 and a relative mass of 1. They are commonly denoted by the symbol 'n'.
4. Neutrons exhibit a unique property. When they are inside the nucleus, they are stable, but when they are in a free state, they are unstable. In about 10 minutes, a free neutron undergoes a process called beta decay, splitting into a proton, an electron, and an electron antineutrino.

5.2 Atomic Model

In your previous classes, you have studied the origin and development of the atomic model. The first genuine explanation of atomic structure came after the formulation of quantum mechanics. Although quantum mechanics has led to a major breakthrough in science, providing a true explanation of the atomic structure, it didn't happen overnight. It is the result of the combined efforts of numerous scientists, and the understanding has gradually developed through continuous endeavors. Two distinct attempts to explain the structure of the atom can be highlighted—the Rutherford atomic model and the Bohr atomic model.

5.2.1 Rutherford's Atomic Model

Scientists knew that there were oppositely charged particles— electrons and protons— within an atom, but they didn't know how they were arranged. British scientist Ernest Rutherford shed light on this matter for the first time and put forward a model based on his experimental data. This model is known as Rutherford's atomic model (Figure 5.1). The model is as follows:

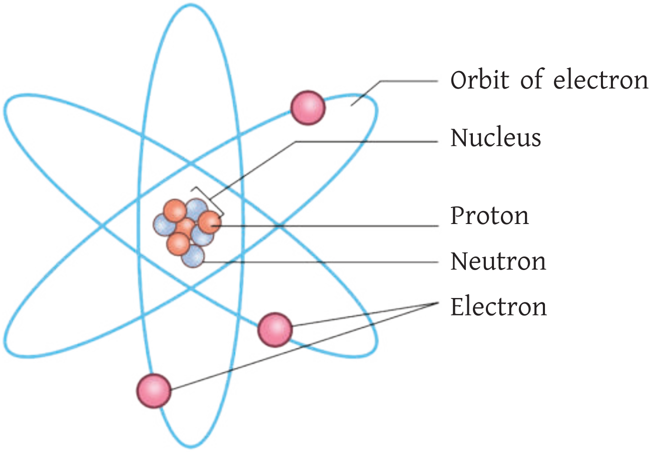


Figure 5.1 : Rutherford's Atomic Model

1. A positive charge is concentrated at the center of an atom, called the nucleus, where most of the atom's mass is located. Inside the nucleus, there are protons, and outside the nucleus, there are electrons. Since the mass of an electron is extremely small in comparison, the combined mass of protons and neutrons within the nucleus is considered as the atom's mass.

2. The nucleus is extremely small, and most of the atom's volume is empty.

3. Rutherford proposed in his atomic model that due to the attractive force of the positive charge at the center, negatively charged electrons revolve around it. He compared the motion of electrons centered around the nucleus to the way planets orbit the sun in our solar system. In other words, electrons revolve the central nucleus along various orbits.

Due to the analogy with the solar system, Rutherford's atomic model is also called the solar system model or the solar model. Moreover, through this model, Rutherford initiated the concept of the nucleus for the first time, which is why it is also referred to as the nuclear model.

Limitations of Rutherford's Atomic Model:

Although the assumption of an extremely small nucleus at the center of the atom was a significant step in understanding the structure of the atom, it could not fully explain the atomic structure. Until then, quantum mechanics had not developed enough to explain the stability of the atom according to Rutherford's model. In this model, it is assumed that electrons revolve around the nucleus, but it fails to explain the stability of electrons according to Maxwell's theory. According to Maxwell's theory, electrons, while revolving around the nucleus, continuously lose energy gradually. As a result, the orbit of electrons becomes smaller, and eventually, they fall into the nucleus (Figure 5.2). From this, it is understood that this model does not explain the stability of the atom. Additionally, this model does not provide any information about the radius, shape, or arrangement of electrons in the electron's orbit.

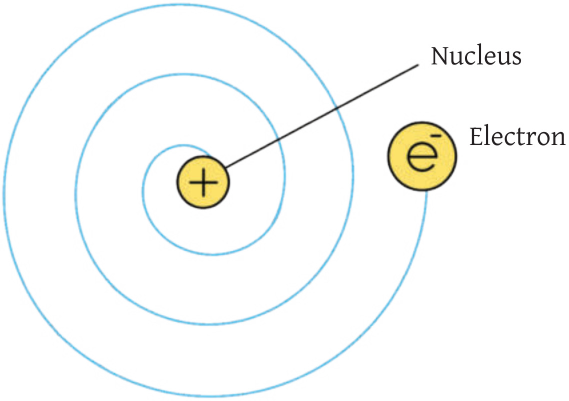


Figure 5.2 : Electrons lose energy and fall towards the nucleus

5.2.2 Bohr's Model

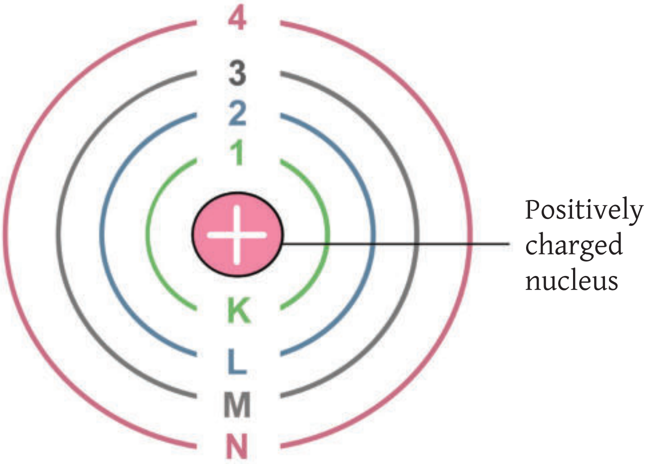


Figure 5.3 : Bohr's Atomic Model: The shells K, L, M, N are depicted

In 1913, scientist Niels Bohr addressed the limitations of Rutherford's atomic model and proposed a new atomic model. At that time, scientists began to explore the fundamental concepts of quantum mechanics, and these concepts were applied in developing this model. The main features of Bohr's atomic model are:

1. Electrons within an atom do not revolve around the nucleus in any arbitrary orbit. Instead, they only revolve in specific permitted circular orbits of fixed radii. While staying in their stable orbits, electrons do not emit or absorb energy.

2. These stable orbits are represented by the number 'n,' where the values of n are 1, 2, 3, 4, … and so on. These orbits are also referred to as K, L, M, N shells (Figure 5.3). These are also termed as energy levels or shells. Note that when the value of n is lower, it is referred to as a lower energy level, and when the value of n is

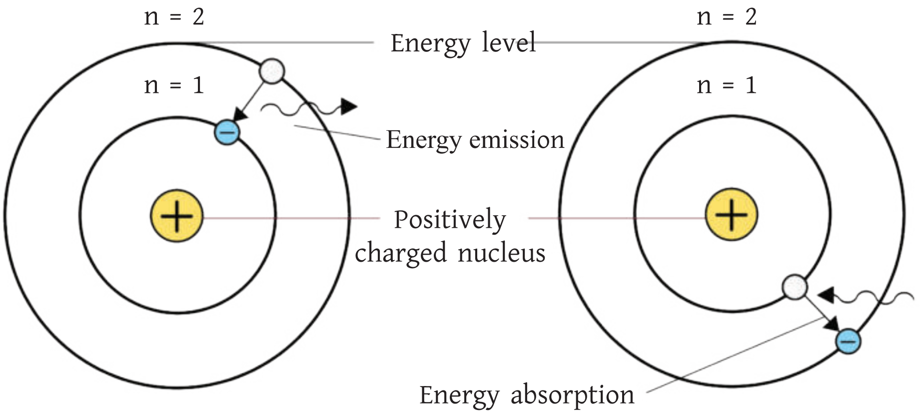


Figure 5.4 : Bohr's Atomic Model. The principal energy level (n), demonstration of energy absorption or emission when an electron transitions from one energy level to another

higher, it is called a higher energy level.

3. When an electron revolves in its principal energy level, it neither loses nor gains energy. If energy is supplied externally, the absorbed energy makes the electron move from a lower energy level to a higher one (Figure 5.4). Conversely, if an electron moves from a higher energy level to a lower one, energy is emitted. The amount of absorbed or emitted energy (ΔE) during the transition between two energy levels (E_1, E_2) is determined by Planck's equation:

$$\Delta E = E_2 - E_1 = h\nu$$

Here, ΔE is the absorbed or emitted energy, *h* is Planck's constant ($6.626 \times 10^{-34}\ m^2kg/s$), and ν is the frequency of the absorbed or emitted electromagnetic radiation. Bohr's model successfully explained the spectral lines produced by hydrogen (H) atoms using this absorbed energy.

Limitations of Bohr's Atomic Model

Despite the remarkable success of Bohr's atomic model, it too had some limitations. While it successfully explained the atomic spectrum of an atom with single-electron, it faced challenges in explaining the spectral lines of multi-electron atoms. According to Bohr's atomic model, when an electron transitions from one energy level to another, a specific amount of energy causes the appearance of a single line in the atomic spectrum. However, upon closer examination, it was observed that each line is, in fact, a collection of numerous closely spaced lines, indicating the presence of various energy levels between the two main levels.

5.3 Electronic Configuration of Atoms

Rutherford and Bohr's model, along with the collective efforts of numerous scientists, gradually unveiled the mysteries of atomic structure and how electrons are arranged in atoms. As mentioned earlier, to fully comprehend this fascinating world, one needs to delve into the realm of quantum mechanics. Those of you pursuing advanced studies in physics will have the opportunity to explore the subject comprehensively and holistically. However, even without delving into the details of how these rules came about, you can understand the basics of how electrons are organized in an atom by simply applying these rules.

You've already gained some insights into the rules governing electron configuration in the previous classes. You know that according to Bohr's atomic model, the energy levels of electrons in an atom are referred to as principal energy levels, denoted by the symbol 'n'. Each principal energy level has a maximum electron-holding capacity given by the formula $2n^2$, where n = 1, 2, 3, 4, … etc., representing the number of the energy level. The corresponding energy levels are often denoted as K, L, M, N, and so forth, also known as shells. For example, when $n = 1$, $2n^2 = 2 \times (1)^2 = 2$, meaning the first energy level or shell (K shell) can accommodate a maximum of 2 electrons. Similarly, when $n = 2$, $2n^2 = 2 \times (2)^2 = 8$, indicating that the second energy level or shell (L shell) can hold a maximum of 8 electrons. By applying this pattern, you can determine the maximum electron capacity for the subsequent energy levels or shells. To further understand and practice these rules, let's explore the electron configurations of some molecules in the table below.

Table: Electron Configuration of Atoms

Atomic Number	Element	n = 1 K Maximum 2 Electrons	n = 2 L Maximum 4 Electrons	n = 3 M Maximum 18 Electrons	n = 4 N Maximum 32 Electrons
1	H	1			
2	He	2			
3	Li	2	1		
11	Na	2	8	1	
18	Ar	2	8	8	
19	K	2	8	8	1
20	Ca	2	8	8	2
21	Sc	2	8	9	2
22	Ti	2	8	10	2
23	V	2	8	11	2
24	Cr	2	8	13	1
25	Mn	2	8	13	2
26	Fe	2	8	14	2
30	Zn	2	8	18	2

In the above table, you can see that the atomic number of Hydrogen (H) is 1, indicating that it has 1 electron. Therefore, this electron is entering the first energy level or the K shell. Similarly, according to the rules of electron configuration in atoms, for Lithium (Li) with an atomic number of 3, it has 2 electrons in the first energy level or K shell. Following the electron configuration rules, since the first energy level (K shell) cannot accommodate more than 2 electrons, the third electron enters the second energy level or L shell. In the case of Sodium (Na), the rules dictate that the first energy level (K shell) holds 2 electrons, the second energy level (L shell) holds 8 electrons, and the third energy level (M shell) holds 1 electron.

For all the examples in the table, the electron configurations in atoms follow the $2n^2$ rule. In other words, the number of electrons in an energy level does not exceed $2n^2$. However, in some cases, the lower energy level is not completely filled, and electrons start to enetr the next higher energy level. For instance, we can see from the table, Potassium (K) and Calcium (Ca) have atomic numbers 19 and 20, respectively, and both have the maximum electron-holding capacity of 18 in the third energy level (M shell). However, the 19th electron of Potassium and the 19th and 20th electrons of Calcium start populating the fourth energy level (N shell) without completely filling the third energy level (M shell).

To understand why electrons sometimes leave lower energy levels incomplete and move to higher energy levels, we need to explore a new concept, which is the sub-energy level of electrons.

5.4 Concept of Orbital

We know that the principal energy levels are represented by n. These energy levels are further divided into sublevels, denoted by the English letter l. Here, the value of l ranges from 0to n-1. Sublevels are referred to as orbitals. Besides the numerical designations (0, 1, 2, 3...), these orbitals also have distinct names: s, p, d, and f. Now, let's explore the concept of sublevels (l) and orbitals based on the value of the principal energy level (n):

When $n = 1$, there can be only one value for l, which is $n – 1 = (1 - 1) = 0$. In this case, there will be one orbital, and it will be represented as 1s.

For $n = 2$, the maximum value for l is $n – 1 = (2 - 1) = 1$. Therefore, there can be two values for l: $l = 0$ and $l = 1$. This means there will be two orbitals, namely 2s and 2p.

When n = 3, the maximum value for l is n – 1 = (3 - 1) = 2. Thus, there can be three values for l: l = 0, 1, and 2. This leads to three orbitals: 3s, 3p, and 3d. We can observe a similar pattern for n = 4, where l can be 0, 1, 2, or 3, resulting in four orbitals: 4s, 4p, 4d, and 4f.

For n = 5, there will be five orbitals. However, since the first four orbitals (5s, 5p, 5d, and 5f) can accommodate all the electrons, there is no need for additional fifth or other orbitals after the fourth orbital. This holds true for n = 6, 7, and 8 as well.

We have divided each principal energy level into its sublevels or orbitals. Now, we need to determine how many electrons can be accommodated in each sublevel or orbital. The way its determined can be properly demonstrated by solving the equations of quantum mechanics, but here we will only mention the results. The number of electrons in an orbital is given by the formula 2(2l + 1). In other words,

For l = 0, the maximum number of electrons in s orbital of any n is 2(2 × 0 + 1) = 2.

For l = 1, the maximum number of electrons in p orbital of any n is 2(2 × 1 + 1) = 6.

For l = 2, the maximum number of electrons in d orbital of any n is 2(2 × 2 + 1) = 10.

For l = 3, the maximum number of electrons in f orbital of any n is 2(2 × 3 + 1) = 14.

Now, you can easily see that for any n, the total number of electrons found by the sum of electrons in all orbitals follows the $2n^2$ rule!

Food for Thought:

Can you mathematically demonstrate that for any given value of n, the sum of electrons in all orbitals is $2n^2$. In other words, is $\sum_{0}^{n-1} 2(2l + 1) = 2n^2$?

The table below illustrates the main energy levels (n = 1 to 4), the possible sublevels for each energy level, the names of the orbitals in the respective sublevels, the total number of electrons in each orbital, and the total electron count in the main energy level:

Main Energy Level (n)	Value of Sublevel l	Name of Orbital	Symbol of Orbital	Total Number of Electrons in Orbital 2(2l+1)	Total Number of Electrons in Main Energy Level $2n^2$
1	0	s	1s	2	2
2	0	s	2s	2	2 + 6 = 8
	1	p	2p	6	
3	0	s	3s	2	2 + 6 + 10 = 18
	1	p	3p	6	
	2	d	3d	10	
4	0	s	4s	2	2 + 6 + 10 + 14 = 32
	1	p	4p	6	
	2	d	4d	10	
	3	f	4f	14	

5.5 Principles of Electron Configuration in Atoms

The principles of electron configuration in atoms are described below:

1. According to the electron configuration principles in atoms, electrons fill the orbitals starting from the lowest energy level, and then proceed to fill higher energy level orbitals in sequence. In simpler terms, electrons enter orbitals with lowest energy level first, and then gradually enter the higher energy level orbitals.

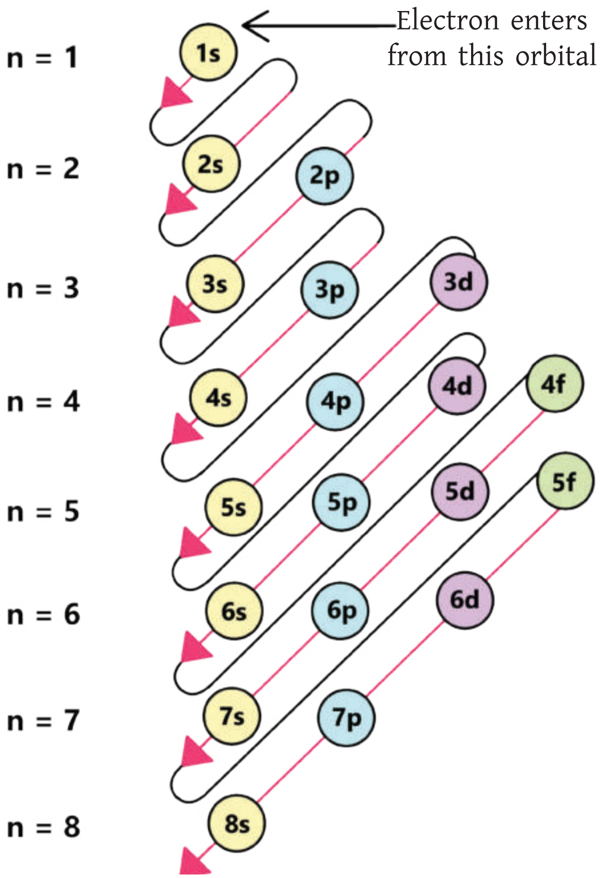
Now, the question arises: How can we determine which orbital has higher or lower energy? To understand this, we need to calculate and compare the sum of the value of principal energy level (n) and the sublevel (l) for two orbitals. The orbital with a lower value of (n + l) has lower energy, and the one with a higher value has higher energy.

For example, let's compare the energies of the 3d and 4s orbitals:

$$3d: (n + l) = (3 + 2) = 5$$

$$4s: (n + l) = (4 + 0) = 4$$

Here, we observe that the 4s orbital in the fourth energy level has lower energy than the 3d orbital in the third energy level. Therefore, following the principles stated above, electrons will first enter the 4s orbital and then go into the 3d orbital.



Electron enters from this orbital

Figure 5.5 : Filling Order of Atomic Orbitals

2. If the values of (n + l) are equal for two orbitals, the orbital with a lower principal energy level (n) has lower energy, and electrons will enter that orbital first. For instance, consider the comparison between the 3d and 4p orbitals:

$$3d: (n + l) = (3 + 2) = 5$$

$$4p: (n + l) = (4 + 1) = 5$$

In this case, both orbitals have the same (n + l) value of 5, but since the value of n for the 3d orbital is 3, and for the 4p orbital is 4, the 3d orbital has lower energy. Consequently, electrons will enter the 3d orbital before the 4p orbital.

By applying these two simple rules, we can arrange all orbitals in order of increasing energy levels:

1s <2s <2p <3s <3p <4s <3d <4p <5s <4d <5p <6s <4f <5d <6p 7s 5f <6d <7p <8s

If we connect these orbitals by a line, we can observe the energy level pattern (Figure 5.5).

3. We know that in an atom, the s subshell or energy level can have a maximum of 2 electrons, the p subshell can have a maximum of 6 electrons, the d subshell can have a maximum of 10 electrons, and the f subshell can have a maximum of 14 electrons. Therefore, when arranging electrons for any atom, we must start from the subshell with the lowest energy level and fill the orbitals until they reach their maximum holding capacity. After filling an orbital, we move to the next energy level and continue placing electrons until all the electrons are placed.

Now, let's try to arrange electrons for any atom. To make electron arrangement more understandable, we write the number of electrons on each orbital symbol. Following the above rules, here are the electron arrangements for some elements:

O (8) → $1s^2\ 2s^2\ 2p^4$

Al (13) → $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$

K (19) → $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$

Ca (20) → $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$

Sc (21) → $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^1$

Previously, we observed that Potassium (K) and Calcium (Ca) entered the fourth energy level (n = 4) without fully filling their third energy level (n = 3). Now, you can surely understand the reason. To complete the third energy level, electrons must enter the 3d orbitals. However, the energy of the 3d orbitals is higher than the energy of the 4s orbitals. Therefore, electrons enter the 4s orbital, leaving the 3d orbitals incomplete. Another example is Scandium (Sc), where electrons from the 19th and 20th positions fully occupy the 4s orbital and then comes back to the 3d orbital with the 21st electron. A similar electron configuration is seen in Iron (Fe, atomic number 26):

Fe (26) → $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^6$

If electron arrangement is not completed in a primary energy level (n) before starting in the next energy level, electrons may occasionally move back and forth between energy levels. Therefore, for clarity, the subshells or orbitals of the main energy level (n) are written sequentially. Thus, Scandium (Sc) and Iron (Fe) have all the third subshells written sequentially before moving to the fourth subshell.

$$\text{Sc (21)} \rightarrow 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^1\ 4s^2$$

$$\text{Fe (26)} \rightarrow 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ 4s^2$$

5.6 Exceptions to the General Rules of Electron Configuration

There are exceptions to any rule. Even in the electron configuration, certain deviations can be observed from the general rules, and behind these exceptions, there are also logical reasons. For instance, it is commonly observed that orbitals of the same subshell, such as p and d orbitals, are sometimes half-filled (e.g., p^3, d^5) instead of being completely filled (e.g., p^6, d^{10}), because these create a more stable electron configuration. For example, the electron configuration of copper (Cu) should generally be as follows:

$$\text{Cu (29)} \rightarrow 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9\ 4s^2$$

However, the 3d orbital becomes more stable if it is completely filled. To achieve this, an electron from the 4s orbital moves to the 3d orbital. Consequently, the electron configuration of copper (Cu) becomes:

$$\text{Cu (29)} \rightarrow 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^1$$

Similar exceptions can be observed in the electron configuration of chromium (Cr).

Food for Thought:

Try writing the correct electron configuration for Cr (24) according to the above rules.

5.7 Atomic Mass or Relative Atomic Mass

Let's assume you've been asked to find the mass of an atom. We know that the mass of an atom, or atomic mass, refers to the total mass of the electrons, protons, and neutrons present in that atom. At the beginning of this chapter, the masses of electrons (9.109 $\times 10^{-31}$ kg), protons (1.673 $\times 10^{-27}$ kg), and neutrons (1.675 $\times 10^{-27}$ kg) are provided. Hence, we can now determine the mass of any atom. However, upon inspection, we notice that these masses are very small. In practical applications, we often choose a more convenient unit for measurement. We use the mass of the sun as reference to measure the mass of celestial bodies in space, tons for the engines of trains, kilograms for the weight of elephants, grams for the amount of sugar in a soft drink, and milligrams for the effective chemical substances in medicines. Just like that, scientists have established a suitable unit for expressing the mass of atoms. This unit is called the atomic mass unit (amu), denoted by the symbol 'u'. The atomic mass unit is defined as (1)/(12)th of the mass of a carbon-12 (^{12}C) isotope. Therefore,

$$1\ \text{u} = 1.661 \times 10^{-27}\ \text{kg}$$

In other words, in this new unit,

$$\text{Mass of } ^{12}\text{C Isotope} = 12\text{u}$$

And,

$$\text{Mass of Electron} = 0.00054858\ \text{u}$$

$$\text{Mass of Proton} = 1.007276\ \text{u}$$

$$\text{Mass of Neutron} = 1.008664\ \text{u}$$

You might think that since atoms are composed of electrons, protons, and neutrons, and we know the individual masses of these particles, we can now determine the mass of any atom. However, this is not entirely true. Although we can estimate the mass of an atom using the sum of the masses of its electrons, protons, and neutrons, we cannot use this calculated mass as the actual mass. For example, if we try to calculate the mass of a ^{12}C atom using the total mass of electrons, protons, and neutrons in this new unit, it should be 12u. Since a ^{12}C atom contains 6 electrons, 6 protons, and 6 neutrons, the calculated mass would be:

$$^{12}C \text{ atom's mass} = 6 \times (0.00054858 + 1.007276 + 1.008664) \text{ u} = 12.09893148 \text{ u}$$

You can see that it is almost 12u but slightly more, about 0.8% more. This is not the case only for ^{12}C but for any atom. If we calculate the mass of an atom by adding the masses of electrons, protons, and neutrons, the calculated mass will be slightly more than the actual mass. Since the mass of electrons is negligible compared to protons and neutrons, and we don't consider this mass when determining the mass of an atom, we can assume that during the formation of the nucleus by combining protons and neutrons, some mass is lost due to some reason. You may have heard about the nuclear force before. Inside the nucleus, protons and neutrons attract each other by the nuclear force, and the lost mass is transformed into energy according to the relativistic equation $E = mc^2$. This energy keeps the protons and neutrons bound inside the nucleus. So, you can understand that knowing only the number of neutrons and protons in an atom allows us to estimate their approximate atomic mass, but determining the actual atomic mass from this information is not possible. For this reason, scientists have worked hard to determine and note down the atomic masses of all elements in different isotopes.

Atomic Mass of the Isotpoes of a few Elements

Element	Isotope	Isotope
C	^{12}C	12 u
Carbon	^{13}C	13.003355
Cl	^{35}Cl	34.968 u
Chlorine	^{37}Cl	36.956 u

Academic year 2024

Cu Copper	^{63}Cu	62.9295975(6)
	^{65}Cu	64.9277895(7)
Ag Silver	^{107}Ag	106.9050915(26)
	^{109}Ag	108.9047558(14)
U Uranium	^{235}U	235.0439299(20)
	^{238}U	238.0507882(20)

Now, let’s ponder a completely different question. Let's assume you want to know the atomic mass of chlorine (Cl) gas. However, chlorine has two isotopes, one Cl(35) and the other Cl(37), with atomic masses of 34.968u and 36.956u, respectively. So, which one will you consider for the atomic mass of chlorine (Cl) gas? Scientists have prepared a concise answer to this question as well. When a molecule has multiple isotopes, their weighted average is calculated based on the percentage abundance to determine the atomic mass of the molecule. Since:

The natural abundance of Cl (35) is (75.77%) with an atomic mass of 34.968u and

The natural abundance of Cl (37) is (24.23%) with an atomic mass of 36.956u

Weighted average atomic mass of chlorine = (75.77 x 34.968 + 24.23 x 34.956)/100=35.45u

So, if you were to take any random chlorine atom from a sample, it would likely have an atomic mass of 34.968u or 36.956u, but it would not be exactly 35.45u. However, the atomic mass of chlorine is conventionally considered as 35.45u. In the upcoming chapters, you will see this as the number being used as the atomic mass of chlorine.

In chemistry, the term ‘atomic weight’ is widely used, although in the field of physics, the term ‘weight’ has a specific meaning (weight is the force obtained by multiplying mass by $9.8 m/s^2$, and its unit is Newton N). However, in chemistry, the term ‘atomic weight’ is used to represent the average relative atomic mass without a specific unit. In other words, dividing the atomic mass of an element by 1u gives the relative atomic mass. It is a numerical quantity that represents a comparison between two masses, so it has no unit.

If you know the atomic number and the percentage abundance of an element, you can calculate the relative average atomic mass. Now, can you reverse this process? If you have two isotopes of a molecule, and you know the average atomic mass, how can you determine the natural abundance of the isotopes?

Food for Thought:

In nature, there are two isotopes of copper, ^{63}Cu and ^{65}Cu, with an average relative atomic mass of 63.5. Can you determine the natural abundance of ^{63}Cu and ^{65}Cu?

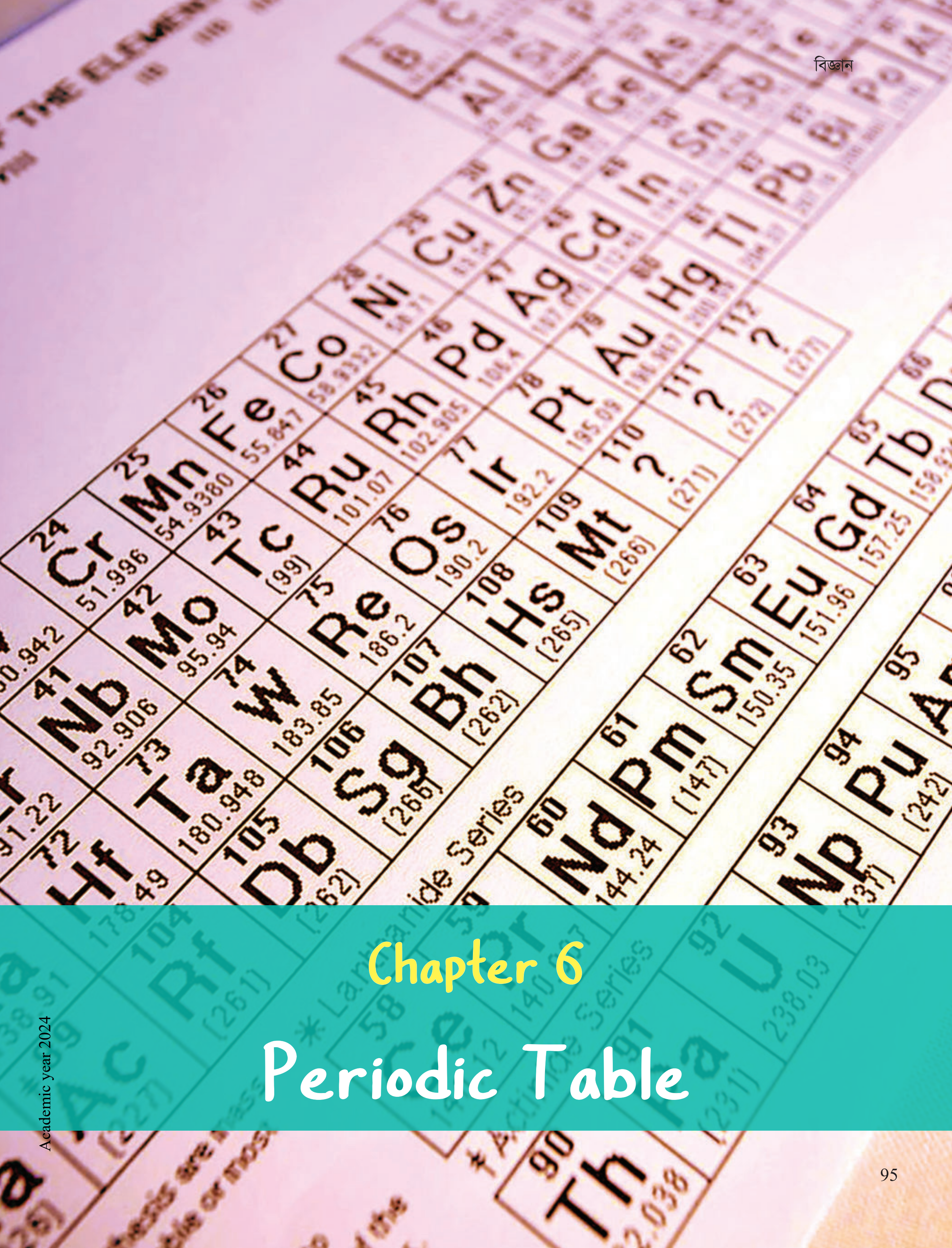
Food for Thought: If you know the average relative atomic mass of three isotopes of a molecule, can you determine their percentage natural abundance in nature?

5.8 Relative Moleculer Mass

The mass of a molecule determined by using the relative atomic mass is referred to as the relative moleculer mass. In other words, the relative moleculer mass is calculated by multiplying the atomic mass of each atom by the number of atoms present in a molecule and then finding the sum of the results.

Example: What is the relative moleculer mass of CO_2?

Solution: In a CO_2 , there is 1 carbon (C) and 2 oxygen (O) atoms in one molecule. The relative atomic mass of carbon is 12, and the relative atomic mass of oxygen is 16. Therefore, the relative moleculer mass of CO_2 is $1 \times 12 + 2 \times 16 = 44$.



Chapter 6

Periodic Table

Chapter 6

Periodic Table

In this chapter, the following topics are discussed:

- ☑ Concept of Periodic table
- ☑ Determining the position of elements in the periodic table
- ☑ Periodic properties of elements
- ☑ Special names of elements in various groups of the periodic table
- ☑ Advantages of the periodic table

Having an understanding of the physical and chemical properties of the 118 elements present in the periodic table makes it easier to comprehend various aspects related to the study of chemistry. Some elements exhibit similar properties. Therefore, scientists have long attempted to organize all elements with similar properties into the same group and create a table that shows the pattern for these elements. This endeavor has been ongoing for a long time and has undergone various changes and modifications, eventually leading to the modern periodic table we are familiar with today. Hence, the periodic table stands as a remarkable contribution by scientists. In this chapter, we will try to explore the concept of the periodic table and discuss the various aspects related to the elements present in the periodic table.

6.1 Concept and Background of the Periodic Table

The culmination of various ideas about elements and their properties put forward by the scientists are presented into the concept of the periodic table. The periodic table is not the result of an individual scientist's single effort or research; rather, it has evolved over many years of continuous dedication and research by numerous scientists. A summary of several significant endeavors leading to the formation of the modern periodic table is discussed below:

In 1789, scientist Lavoisier classified some elemental substances into metals and non-metals. These elements include Oxygen (O), Nitrogen (N), Hydrogen (H), Phosphorus

(P), Mercury (Hg), Zinc (Zn), Sulfur (S), etc. Thus, since Lavoisier's time, efforts were made to arrange elements separately into groups so that elements with similar properties would be in a specific category.

Later, scientist Dobereiner attempted to organize elements with similar properties into groups of three, based on their atomic masses. He observed that the atomic mass of the second element in the triad was approximately the average of the first and third elements, a concept known as ‘Dobereiner's triads’. In this way, he identified Chlorine (Cl), Bromine (Br), and Iodine (I) as the first triad based on their atomic masses.

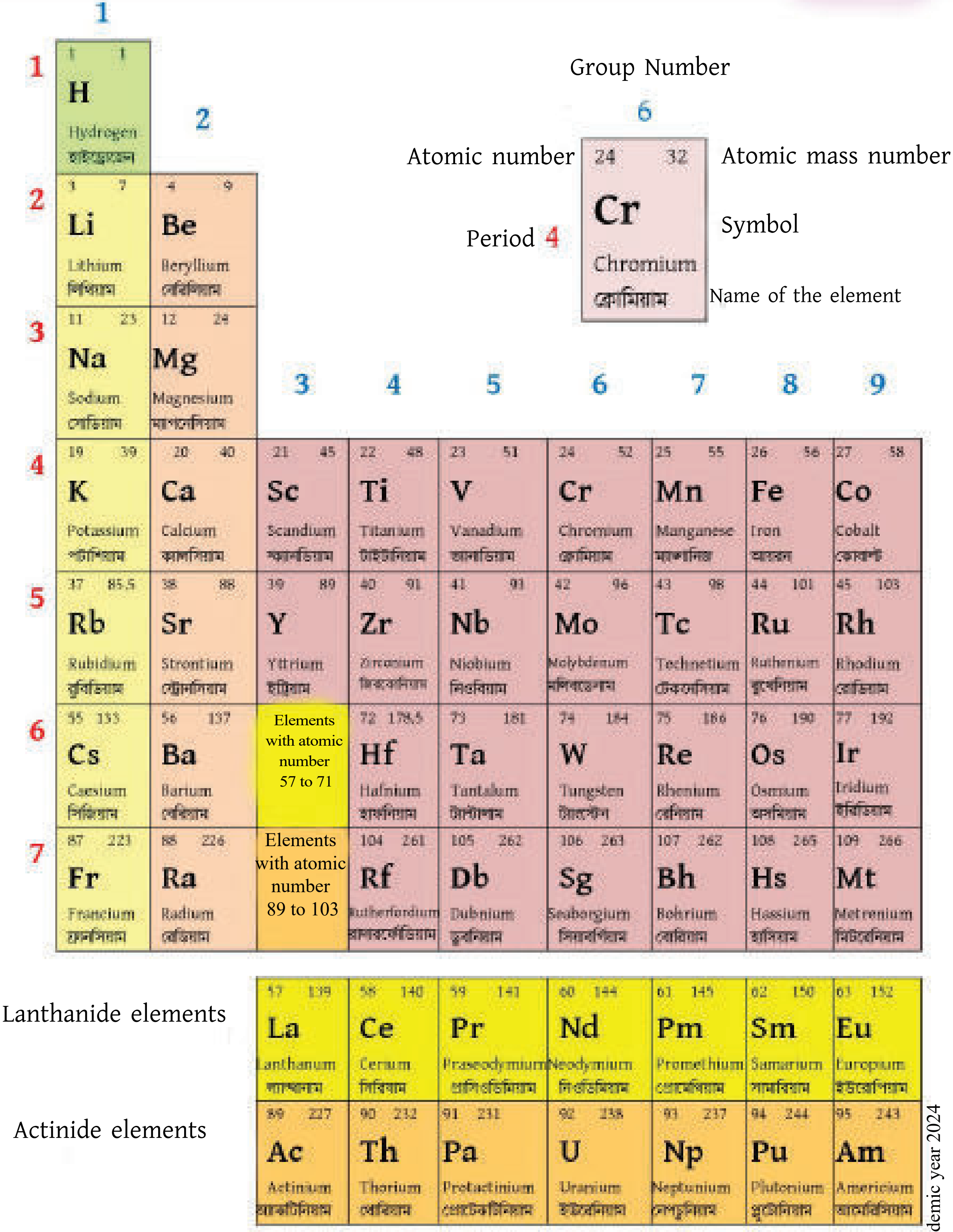
Later, English scientist John Newlands provided a rule for all discovered elements until the year 1829, known as ‘Newlands' Octaves’. He observed that according to this rule, when elements are arranged in increasing order of atomic masses, similarities in the physical and chemical properties of an element are found with its eighth element.

Then, in 1869, Russian scientist Mendeleev, after examining the physical and chemical properties of all known elements, formulated a periodic law that correlated the properties of elements with their atomic masses. The law stated, “When the elements are arranged in order of increasing atomic mass, certain sets of properties recur periodically”. Following this rule, he organized the then-discovered 63 elements into a table with 12 horizontal rows and 8 vertical columns, arranging them based on their increasing atomic masses. He observed that elements in the same column exhibited similar physical and chemical properties. Additionally, there was a periodic change in properties from the beginning to the end of each row. This arrangement was named the ‘Periodic Table’.

Mendeleev's success with this periodic table lies in predicting the existence of certain elements accurately. It is noteworthy that at that time, only 63 elements were discovered. As a result, some spaces in the periodic table remained vacant, and Mendeleev made predictions about the properties of elements that would fill those gaps, which were later confirmed or found to be accurate as more elements were discovered.

The success of Mendeleev's periodic table was remarkable, but it had some limitations. For instance, the way Mendeleev arranged elements in his periodic table based on atomic masses had a discrepancy. According to this rule, Argon (Ar) with an atomic mass of 40 was placed before Potassium (K) with a lower atomic mass of 39. This was done solely to align the properties of elements in the same group. Additionally, hydrogen did not find its correct position in his periodic table.

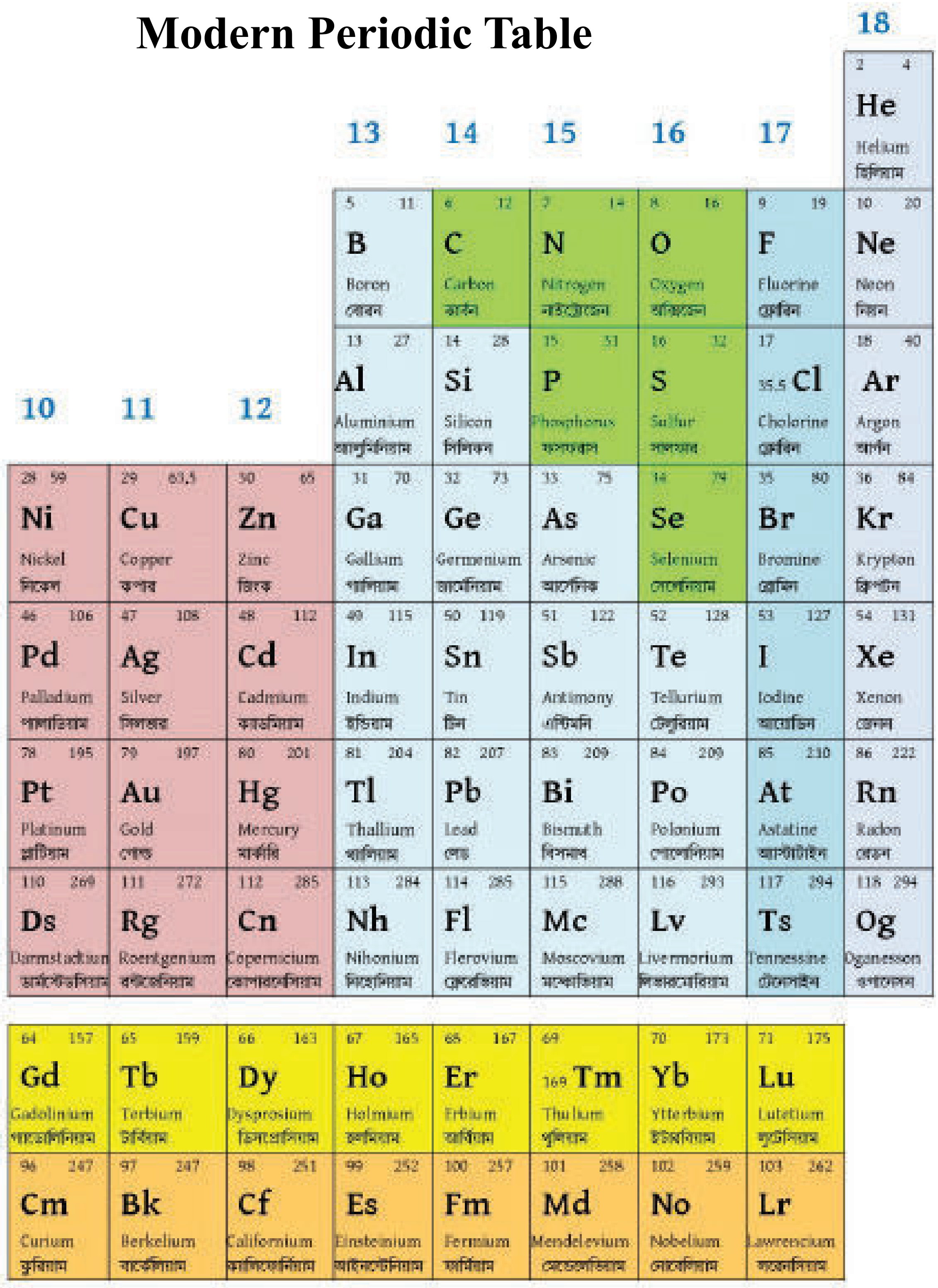
Later, in 1913, scientist Moseley proposed organizing elements in the periodic table



	1	2	3	4	5	6	7	8	9
1	1 1 H Hydrogen হাইড্রোজেন								
2	3 7 Li Lithium লিথিয়াম	4 9 Be Beryllium বেরিলিয়াম							
3	11 23 Na Sodium সোডিয়াম	12 24 Mg Magnesium ম্যাগনেসিয়াম							
4	19 39 K Potassium পটাশিয়াম	20 40 Ca Calcium ক্যালসিয়াম	21 45 Sc Scandium স্ক্যানডিয়াম	22 48 Ti Titanium টাইটেনিয়াম	23 51 V Vanadium ভ্যানাডিয়াম	24 52 Cr Chromium ক্রোমিয়াম	25 55 Mn Manganese ম্যাঙ্গানিজ	26 56 Fe Iron আয়রন	27 58 Co Cobalt কোবাল্ট
5	37 85.5 Rb Rubidium রুবিডিয়াম	38 88 Sr Strontium স্ট্রনশিয়াম	39 89 Y Yttrium ইট্রিয়াম	40 91 Zr Zirconium জিরকোনিয়াম	41 93 Nb Niobium নিওবিয়াম	42 96 Mo Molybdenum মলিবডেনাম	43 98 Tc Technetium টেকনেশিয়াম	44 101 Ru Ruthenium রুথেনিয়াম	45 103 Rh Rhodium রোডিয়াম
6	55 133 Cs Caesium সিজিয়াম	56 137 Ba Barium বেরিয়াম	Elements with atomic number 57 to 71	72 178.5 Hf Hafnium হাফনিয়াম	73 181 Ta Tantalum ট্যান্টালাম	74 184 W Tungsten টাংস্টেন	75 186 Re Rhenium রেনিয়াম	76 190 Os Osmium অসমিয়াম	77 192 Ir Iridium ইরিডিয়াম
7	87 223 Fr Francium ফ্রানসিয়াম	88 226 Ra Radium রেডিয়াম	Elements with atomic number 89 to 103	104 261 Rf Rutherfordium রাদারফোর্ডিয়াম	105 262 Db Dubnium ডুবনিয়াম	106 263 Sg Seaborgium সিবোর্গিয়াম	107 262 Bh Bohrium বোরিয়াম	108 265 Hs Hassium হাসিয়াম	109 266 Mt Metrenium মিটনেরিয়াম
Lanthanide elements			57 139 La Lanthanum ল্যান্থানাম	58 140 Ce Cerium সিরিয়াম	59 141 Pr Praseodymium প্রাসিওডিমিয়াম	60 144 Nd Neodymium নিওডিমিয়াম	61 145 Pm Promethium প্রোমেথিয়াম	62 150 Sm Samarium সামারিয়াম	63 152 Eu Europium ইউরোপিয়াম
Actinide elements			89 227 Ac Actinium অ্যাক্টিনিয়াম	90 232 Th Thorium থোরিয়াম	91 231 Pa Protactinium প্রোটেক্টিনিয়াম	92 238 U Uranium ইউরেনিয়াম	93 237 Np Neptunium নেপচুনিয়াম	94 244 Pu Plutonium প্লুটোনিয়াম	95 243 Am Americium আমেরিসিয়াম

Figure 6.1 : Modern Periodic Table

Modern Periodic Table



10	11	12	13	14	15	16	17	18
								2 4 He Helium হিলিয়াম
			5 11 B Boron বোরন	6 12 C Carbon কার্বন	7 14 N Nitrogen নাইট্রোজেন	8 16 O Oxygen অক্সিজেন	9 19 F Fluorine ফ্লোরিন	10 20 Ne Neon নিয়ন
			13 27 Al Aluminium অ্যালুমিনিয়াম	14 28 Si Silicon সিলিকন	15 31 P Phosphorus ফসফরাস	16 32 S Sulfur সালফার	17 35.5 Cl Cholorine ক্লোরিন	18 40 Ar Argon আর্গন
28 59 Ni Nickel নিকেল	29 63.5 Cu Copper কপার	30 65 Zn Zinc জিংক	31 70 Ga Gallium গ্যালিয়াম	32 73 Ge Germenium জার্মেনিয়াম	33 75 As Arsenic আর্সেনিক	34 79 Se Selenium সেলেনিয়াম	35 80 Br Bromine ব্রোমিন	36 84 Kr Krypton ক্রিপ্টন
46 106 Pd Palladium প্যালাডিয়াম	47 108 Ag Silver সিলভার	48 112 Cd Cadmium ক্যাডমিয়াম	49 115 In Indium ইন্ডিয়াম	50 119 Sn Tin টিন	51 122 Sb Antimony এন্টিমনি	52 128 Te Tellurium টেলুরিয়াম	53 127 I Iodine আয়োডিন	54 131 Xe Xenon জেনন
78 195 Pt Platinum প্লাটিনাম	79 197 Au Gold গোল্ড	80 201 Hg Mercury মার্কারি	81 204 Tl Thallium থ্যালিয়াম	82 207 Pb Lead লেড	83 209 Bi Bismuth বিসমাথ	84 209 Po Polonium পোলোনিয়াম	85 210 At Astatine অ্যাস্টাটাইন	86 222 Rn Radon রেডন
110 269 Ds Darmstadtium ডার্মস্টেডিয়াম	111 272 Rg Roentgenium রন্টজেনিয়াম	112 285 Cn Copernicium কোপারনিসিয়াম	113 284 Nh Nihonium নিহোনিয়াম	114 285 Fl Flerovium ফ্লেরোভিয়াম	115 288 Mc Moscovium মস্কোভিয়াম	116 293 Lv Livermorium লিভারমোরিয়াম	117 294 Ts Tennessine টেনেসাইন	118 294 Og Oganesson ওগানেসন

64 157 Gd Gadolinium গ্যাডোলিনিয়াম	65 159 Tb Terbium টার্বিয়াম	66 163 Dy Dysprosium ডিসপ্রোসিয়াম	67 165 Ho Holmium হলমিয়াম	68 167 Er Erbium আর্বিয়াম	69 169 Tm Thulium থুলিয়াম	70 173 Yb Ytterbium ইটারবিয়াম	71 175 Lu Lutetium লুটেসিয়াম
96 247 Cm Curium কুরিয়াম	97 247 Bk Berkelium বার্কেলিয়াম	98 251 Cf Californium ক্যালিফোর্নিয়াম	99 252 Es Einsteinium আইনস্টাইনিয়াম	100 257 Fm Fermium ফার্মিয়াম	101 258 Md Mendelevium মেন্ডেলেভিয়াম	102 259 No Nobelium নোবেলিয়াম	103 262 Lr Lawrencium লরেন্সিয়াম

based on their atomic numbers instead of atomic masses. When the periodic table was arranged according to this proposal, it was observed that Argon (with atomic number 18) was placed before Potassium (with atomic number 19). Consequently, when arranging elements in the periodic table based on atomic numbers, Mendeleev's discrepancies were rectified.

We know that the International Union of Pure and Applied Chemistry (IUPAC) has discovered a total of 118 elements so far. Among these, the majority are naturally occurring, while some are synthesized in research laboratories.

Therefore, as you can see, scientist Lavoisier initiated the task of forming a table with only 33 elements. Mendeleev worked with 63 discovered and 4 undiscovered elements. Today, the modern periodic table (Figure 6.1) is constructed with 118 elements.

6.2 Characteristics of the Periodic Table

The characteristics of the periodic table are illustrated in Figure 6.2.

6.3 Determining the Position of Elements in the Periodic Table

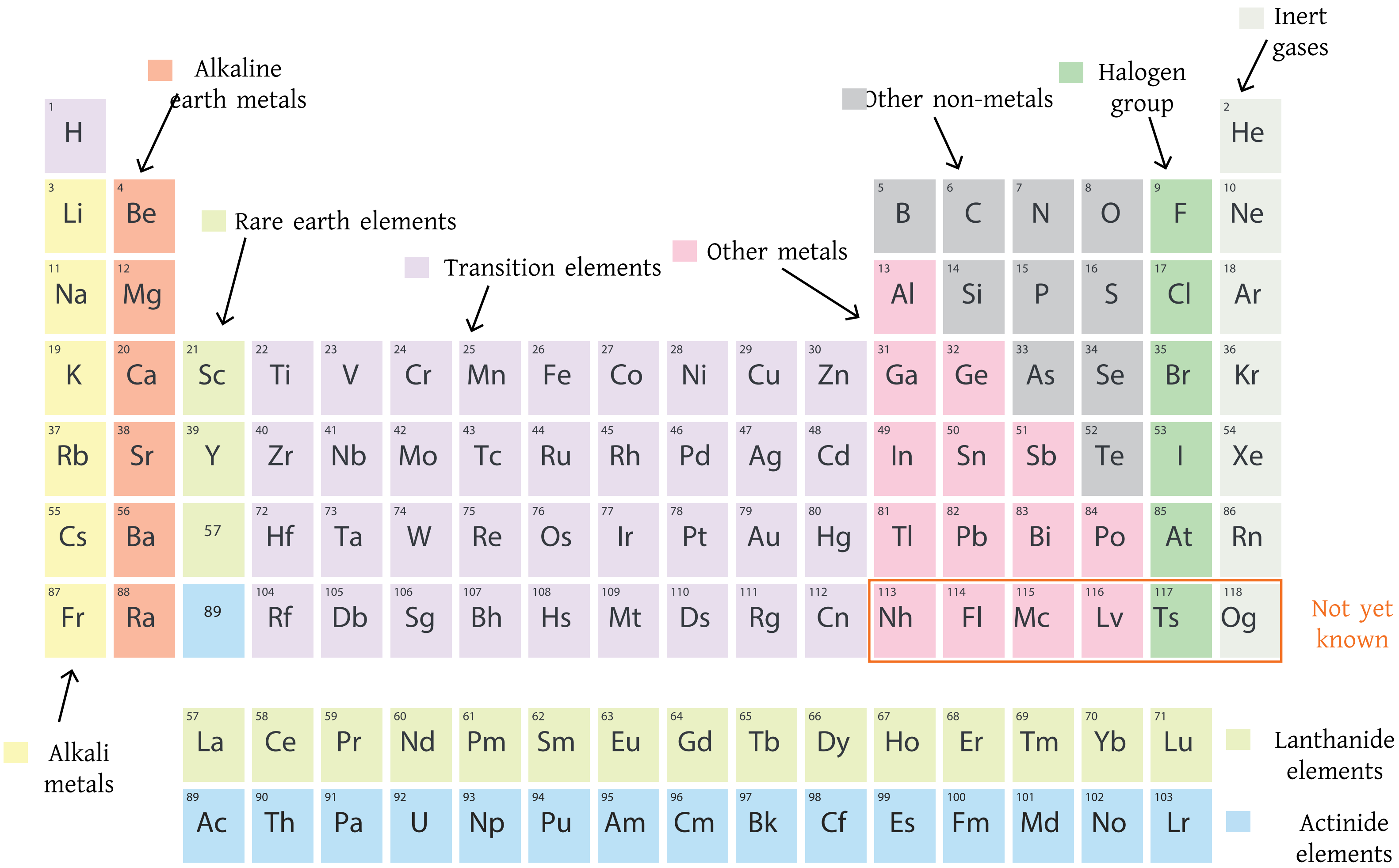
Since the elements in the periodic table are arranged in a sequential manner based on their atomic numbers, therefore, knowing this number alone allows us to determine the position of an element in the periodic table. However, to gain a deeper understanding of the periodic table and familiarize ourselves with the electron configuration of an element, we can further investigate to which group and period an element belongs. Below, we shed light on the process of determining the position of an element in the periodic table with examples:

A. Determining the Periodic Number of an Element

If we observe the electron configuration of any element, the number of the outermost or the highest principal energy level in the electron configuration of that element is the Period number of that element. For example, the electron configuration of Lithium (Li) is:

Li(3) $\longrightarrow 1s^2\ 2s^2$ In this case, the outermost principal energy level for Li is 2. Therefore, Lithium is located in period 2.

Similarly, for Potassium (K), the electron configuration is as follows: K(19) $\longrightarrow 1s^2\ 2s^2\ 2p^2$



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Figure 6.2 : Characteristics of the Periodic Table

$3s\ ^{2}3p^{2}\ 4s^{2}$. Here, the outermost principal energy level for K is 4. Hence, Potassium is positioned in the 4th period of the periodic table.

B. Determining the Group Number of an Element

There are several rules to determine the group number of an element in the periodic table. These rules are:

Rule 1: If an element has only s orbitals outside or in the highest principal energy level, then the total number of electrons in the s orbital is the group number of that element.

Example: Hydrogen (H) has electron configuration: H(1) $\longrightarrow 1s^{1}$. Here, there is one electron in the s orbital. Therefore, according to the rule, the group number is 1.

Rule 2: If an element has both s and p orbitals in the outermost principal energy level, then the group number of that element is found by adding 10 with the total number of electrons in the s and p orbitals.

Example: Boron (B) has electron configuration: B(5)$\longrightarrow 1s^{2}\ 2s^{2}\ 2p^{1}$. In this case, there are a total of 2 electrons in the s orbital and 1 electron in the p orbital in its outermost principal energy level. Therefore, the group number of Boron is (2 + 1 + 10) = 13.

Rule 3: To determine the group number of an element with s orbitals in the outermost principal energy level, the number of electrons in the s orbital needs to be considered. If there are d orbitals in the previous principal energy level, the electron count in those d orbitals must also be included. The sum of electrons in these s and d orbitals gives the group number of the element.

Example: Iron (Fe) has electron configuration: Fe(26) $\longrightarrow 1s^{2}\ 2s^{2}\ 2p^{6}\ 3s^{2}\ 3p^{6}\ 3d^{6}\ 4s^{1}$. In this case, Iron has s orbitals in the outermost principal energy level and d orbitals in the previous principal energy level. Adding the 6 electrons in the d orbitals and 2 electrons in the s orbitals gives a sum of 8. Therefore, the group number of Iron is (6 + 2) = 8.

The electron configurations of some elements are provided below, illustrating how to easily determine the period number and group number of an element.

Electron Configuration, Period Number & Group Numer of a few Elements

Element	Electron Configuration of Element	Period Number	Group Number
H(1)	$1s^{1}$	1	1 (Rule 1)
He(2)	$1s^{2}$	1	18 (Exception)

B(5)	$1s^2\ 2s^2\ 2p^1$	2	2 + 1 + 10 = 13 (Rule 2)
N(7)	$1s^2\ 2s^2\ 2p^3$	2	2 + 3 + 10 = 15 (Rule 2)
Ne(10)	$1s^2\ 2s^2\ 2p^6$	2	2 + 6 + 10 = 18 (Rule 2)
Mg(12)	$1s^2\ 2s^2\ 2p^6\ 3s^2$	3	2 (Rule 1)
Ti(22)	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^2\ 4s^2$	4	2 + 2 = 4 (Rule 3)

The electron configuration in the outermost level is demonstrated in red color in the above diagram.

Therefore, from the discussion above, it can be understood that by examining the electron configuration of an element, it is possible to determine in which period and in which group it is located. In other words, the electron configuration is the fundamental basis of the periodic table arrangement.

6.4 Some Exceptions in the Periodic Table

Some elements in the periodic table exhibit deviations in their placement based on their characteristics. Below are some such exceptions:

1. Position of Hydrogen (H)

Hydrogen is considered a non-metal. Hydrogen exhibits some properties or characteristics that align with highly reactive positively charged alkaline metals as well as, in some aspects, it aligns with halogen molecules. However, in the periodic tale, it is placed in Group 1 with alkali metals like Na, K, Rb, Cs, Fr. Here, Hydrogen's characteristics is similar to alkali metals in the way that it has one electron in the outermost principal energy level (e.g., H (1) $\longrightarrow 1s^1$; Na (11)$\longrightarrow 1s^2\ 2s^2\ 2p^6\ 3s^1$). On the other hand, halogen elements (e.g., F, Cl, Br, I) possess the characteristic of gaining one electron from another atom. Hydrogen can also gain one electron, aligning with the characteristics of halogens. Notably, most of Hydrogen's characteristics align with alkali metals, hence it is placed in Group 1 with alkali metals.

2. Placement of Lanthanides and Actinides

In the periodic table, the lanthanides and actinides are positioned in periods 6 and 7, respectively, and in Group 3. Essentially, if these series of elements are placed in the main table, they significantly elongated their respective periods. Consequently, these elements are positioned below the main periodic table.

6.5 Periodic Properties of Elements

In the periodic table, it can be observed that the characteristics of elements are systematically repeated with their atomic numbers. This means that these characteristics are periodically displayed or follow a specific trend. These characteristics are known as the periodicity of elements. Various properties of elements exist in the periodic table. These include metallic properties, non-metallic properties, atomic size, electrical conductivity, ionization energy, electron affinity, and more. These properties represent the periodic nature of elements or periodicity, and they are illustrated in Figure 6.3.

A. Metallic Properties

The characteristics of metallic elements include being shiny, making a metallic sound when struck, and being good conductors of heat and electricity. The tendency of an element to lose electrons from its atoms helps determine its metallic properties. Elements that can lose one or more electrons and transform into positively charged ions are referred to as metals. For example, Sodium (Na) loses one electron to form a sodium ion (Na+), therefore, sodium a metal.

$$\mathrm{Na} \longrightarrow \mathrm{Na^+} + e^-$$

In other words, the easier an atom of an element can lose electrons, the greater its metallic properties. According to the periodic table, as we move from left to right across any period, the metallic properties of the elements tend to decrease

B. Non-Metallic Properties

The tendency of an element's atoms to gain electrons determine whether that element is a non-metal. In other words, the easier an atom of an element can gain electrons, the more non-metallic properties it will have. Elements that can gain one or more electrons and transform into negatively charged ions are referred to as non-metals. For example,

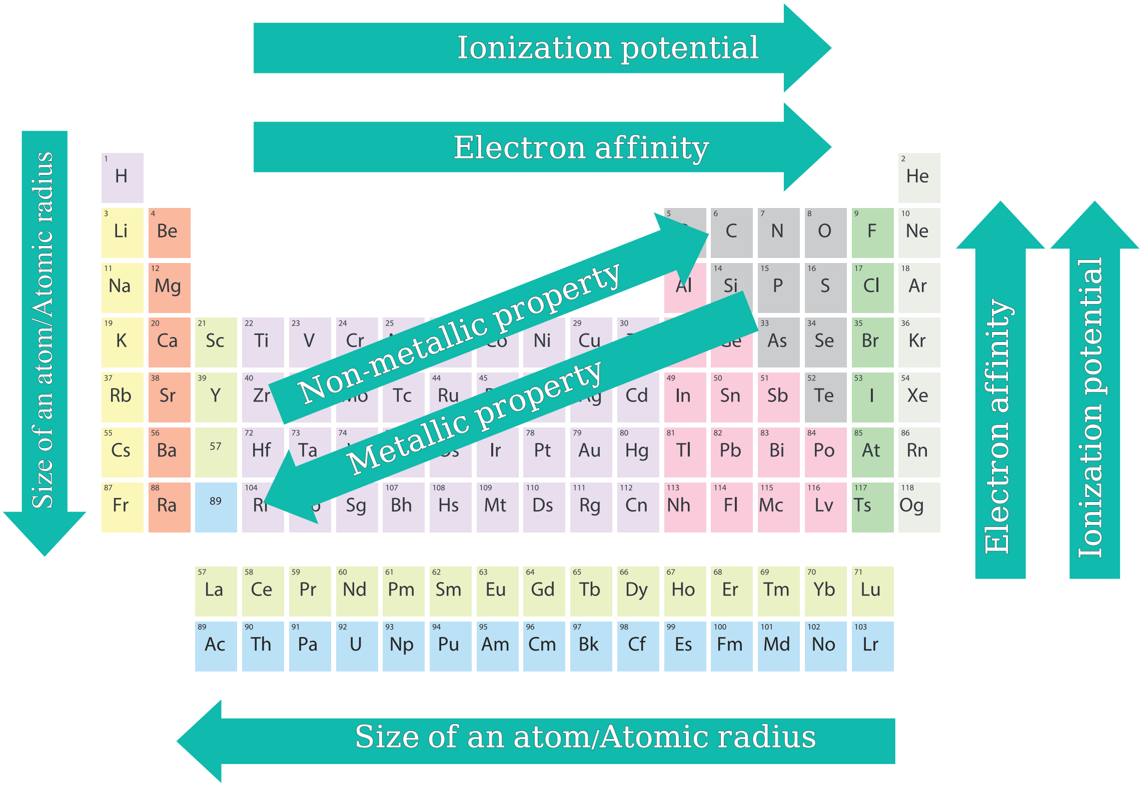


Figure 6.3 : Periodic Properties of Elements in the Periodic Table

Chlorine (Cl) gains one electron to form a negative ion (Cl^-), making Chlorine a non-metal.

$$Cl + e^- \rightarrow Cl^-$$

In the periodic table, as we move from left to right across any period, the non-metallic properties of the elements tend to increase.

Upon close examination of the periodic table, it can be observed that some elements exhibit behaviors resembling both metals and non-metals. These elements are called metalloids. Depending on the circumstances, these metalloids can both lose and gain electrons. Arsenic (As) is an example of such a metalloid.

c) Size of Atoms / Atomic Radius

As we move from left to right across any period of the periodic table, the size of atoms decreases, which means their atomic radius decreases. Conversely, as we move down any group, the size of atoms increases, indicating an increase in atomic radius. The size of an atom is primarily determined by its principal energy level. Upon careful observation of the periodic table, it can be noticed that, as we go from left to right within the same period, the atomic number or the number of electrons increases, but the principal energy level does not. As the atomic number increases, the

number of protons in the nucleus increases, along with the increase in number of electrons located outside the nucleus. The increase in the number of protons inside the nucleus and the increase in the number of electrons outside the nucleus lead to stronger attraction between the electrons and the nucleus. As a result, the electrons move closer to the nucleus, causing the atomic size to decrease or the atomic radius to shrink (Figure 6.4).

Furthermore, as we move downward within the same group of the periodic table, a new energy level is added to the atom. The addition of a new energy level results in an increase in the size of the atom or an increase in the atomic radius.

It is noteworthy that, as we move down the same group, the increase in the number of electrons outside the nucleus, along with the protons in the nucleus, leads to a growing attraction between protons and electrons. Consequently, the size of the atom decreases. However, simultaneously a new energy level is added to each of the atoms as we move down the group, increasing the size or radius of the atom in an amount that is greater

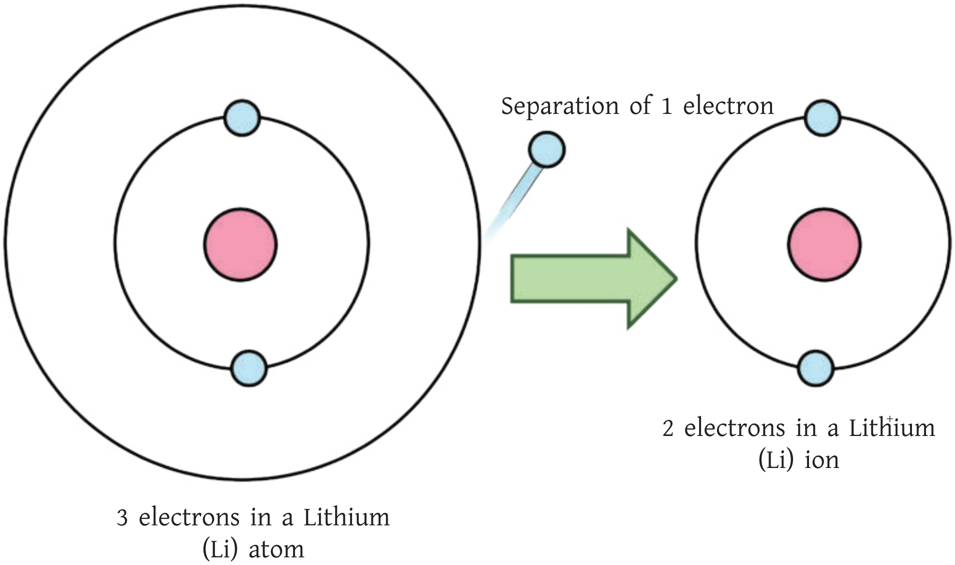


Figure 6.4 : Ionization of Elements

than the reduction by the attraction of the nucleus and the electrons. This results in an overall increase in the size of the atom compared to the one above it in the group.

d)Ionization Energy

Ionization energy is the amount of energy required to remove an electron from an atom in its gaseous state and transform it into a positively charged ion. The ionization energy of an element is influenced by its atomic size. When the atomic radius is smaller, the protons in the nucleus exert a stronger force of attraction on the electrons, requiring more energy to remove them. Therefore, as the atomic radius decreases, the ionization energy increases, and as the atomic radius increases, the ionization energy decreases.

As you've observed, when moving down a group in the periodic table, the atomic size increases, resulting in a decrease in ionization energy. Conversely, when moving from left to right across a period, the atomic size decreases, leading to an increase in ionization energy.

Example: In Period 3, if you examine Sodium (Na), Magnesium (Mg), Aluminum (Al), and Silicon (Si), you'll notice that Silicon, having the smallest atomic radius, has the highest ionization energy. On the other hand, in Group 1, among Lithium (Li), Sodium (Na), Potassium (K), Rubidium (Rb), Cesium (Cs), and Francium (Fr); Lithium, with the smallest atomic radius, exhibits the highest ionization energy.

e)Electron Affinity

The amount of energy released during the addition of an extra electron to the atom of an element in the gaseous state, transforming it into a negative ion, is known as the electron affinity of that element. Similar to ionization energy, as the atomic radius of the molecule decreases, the electron affinity increases, and as the atomic radius increases, the value of electron affinity decreases.

F) Electronegativity

When two atoms are bonded in a molecule, two electrons are needed to make that bond. Both atoms attract the two electrons towards themselves. The atom that can attract the electrons more will have them closer than the other atom. The ability of an atom to attract electrons is called its electronegativity. If two atoms of the same element bond, the electrons will be equally attracted to both atoms, so the electrons will be positioned in the middle of the two atoms. If one atom has higher electronegativity than the other, the electrons will be closer to that atom. In a period, as we move from the left side to the right side, the atomic radius of the atom on the left is greater than that of the atom on the right. As a result, their electronegativity increases from left to right. Francium (Fr) has the lowest (0.7) electronegativity, located furthest to the left, and Fluorine (F) has the highest (4.0) electronegativity, located furthest to the right and on the top, among all elements.

Example: In the 3rd period, Sodium (Na) has lower electronegativity than Chlorine (Cl). In other words, Chlorine has higher electronegativity. In Sodium Chloride (NaCl), we observe that the bond electrons are farthest from Sodium and closest to Chlorine. However, both atoms are in an ionized state when they form this bond.

6.6 Importance of Periodic Table

The Periodic Table has various advantages. A comprehensive picture can be obtained due to all elements being present in a single table. We can understand any characteristic of an element easily and quickly. Even properties of elements not yet discovered can be speculated. Some important advantages of the Periodic Table are discussed below.

a) Facilitation of the Study of Chemistry

You know that so far 118 elements have been discovered. These elements have various physical and chemical properties such as melting point, boiling point, acidity, reactivity, etc. It is not easy to remember or understand all these properties together. However, if you know the general properties of a particular group in the periodic table, you can gain a general idea about all the elements in that group. Therefore, the periodic table plays a crucial role in easily understanding the properties of all the elements present in the 18 groups and 7 periods. Additionally, having a good understanding of the periodic table makes it easier to grasp the characteristics of compounds formed by various elements present in different groups.

b) Conceptualization and Discovery of New Elements

In the periodic table, there were some empty spaces in the 7 periods and 18 groups until a certain time. The elements in these empty spaces were discovered in later times. However, even before their discovery, scientists had made predictions from the periodic table about the properties of the elements that would eventually be discovered and fill those places. Scientist Mendeleev predicted the existence a properties of some undiscovered elements when he placed the 63 then-discovered elements in the periodic table. These predictions later proved to be accurate when those elements were discovered.

c) Role in Research

We know that many new substances are discovered through scientific research. Having some ideas about the properties or characteristics of these new substances in advance can be advantageous in research. Because, understanding what kind of molecules will be needed to create substances with all those properties or characteristics can be inferred from the periodic table.

In addition to the mentioned advantages of the periodic table, there are many more uses that you will learn about in higher classes.

Food for Thought:

Let's assume you have discovered the 119th element. What name would you give to it? Can you make predictions about the properties of this element? What could be its electron configuration?

Chapter 7

Chemical Bonds

Chapter 7 Chemical Bonds

The following topics are discussed in this chapter:

☑ Valence or Valency, Radical
☑ Method of writing chemical formula of compounds
☑ Inert gases and their stability
☑ Chemical bonds and the causes of bond formation
☑ Ionic, covalent and metallic bonding,
☑ Extraction of metals and ores, various alloys

We know that different atoms of the 118 elements discovered so far combine to form different molecules. Therefore, regardless of what we say about substances, all substances are composed of these molecules and atoms. The atoms in a molecule are arranged in an orderly manner. The reason for atoms sticking together in a molecule is the force of attraction or energy which we call a chemical bond. There are different types of chemical bonds, which we will discuss in this chapter.

7.1 Valence or Valency, Radical

You have already got some idea about valence and radicals in the previous class. Here, valency, radical, and valence will be discussed in more detail. Before knowing the valency of atom of an element, we need to know what is meant by the valence electron of that atom.

Valence Electron:

The number of electrons present in the highest energy level or the outermost shell of an atom in an element is called valence electron. For example, the electron configuration of Boron (B) and Oxygen (O) shows that they have 3 and 6 electrons in their outermost shells respectively. Therefore, the valence electron numbers for Boron (B) and Oxygen (O) are 3 and 6, respectively. Figure 7.1 illustrates the valence electrons of boron (B)

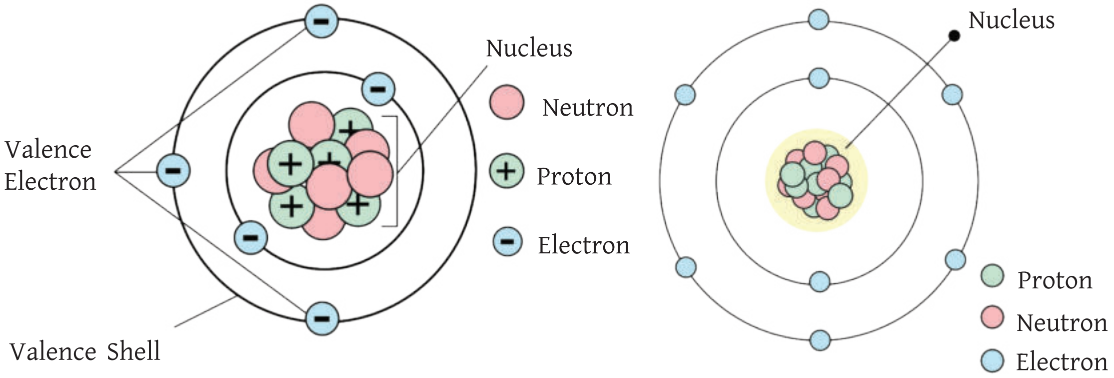


Figure 7.1: The valence electrons of Boron and Oxygen atoms

and oxygen (O).

The electron configuration of Boron (B) and Oxygen (O) is shown below:

$$B\ (5) \rightarrow 1S^2\boxed{2s^2 2p^2}$$

$$O\ (8) \rightarrow 1S^2\boxed{2s^2 2p^4}$$

Outermost shell

You can try to determine the valence electrons of elements such as Nitrogen (N), Phosphorus (P), and Chlorine (Cl) from their electron configuration.

Valency

As you already know, the atoms of an element can gain, lose or share electrons in their outermost shell. Thus, atoms form molecules by gaining, losing, or sharing electrons. The ability of atoms to bond with another atom during the formation of a molecule is called valency. Valency can also be defined as follows:

The number of hydrogen (H) atoms or chlorine (Cl) atoms that can bond with an atom of an element is the valency of that element. Similarly, the valency of a molecule is twice the number of oxygen atoms that can bond with one atom of that molecule.

For example,

Ammonia (NH_3): One atom of Nitrogen (N) is bonded to three atoms of Hydrogen (H). Therefore, the valency of Nitrogen is 3.

Sodium chloride (NaCl): One atom of Sodium (Na) is bonded to one atom of Chlorine

(Cl). Therefore, the valency of Sodium is 1.

Calcium oxide (CaO): One atom of Calcium (Ca) is bonded to one atom of Oxygen (O). Therefore, the valency of Calcium is 2.

However, some elements have multiple valencies. For example, Iron (Fe) has two valencies.

$FeCl_2$: One atom of Iron (Fe) is combined with 2 atoms of Chlorine (Cl). The valency of Iron is 2.

$FeCl_3$: One atom of Iron (Fe) is combined with 3 atoms of Chlorine (Cl). The valency of Iron is 3.

When an element has multiple valencies, it is called variable valency. Therefore, the variable valencies of iron are 2 and 3.

Radicals

A group of one or more atoms of an element that behaves like an ion of the element, with a positive or negative charge, is called a radical. A radical has a charge, which can be either positive or negative. This very charge is its valency, and it is always a whole number.

Example : Radical

Name of the Radical	Formula	Charge	Valency
Carbonate	CO_3^{2-}	-2	2
Ammonium	NH_4^+	+1	1
Sulphate	SO_4^{2-}	-2	2
Phosphate	PO_4^{3-}	-3	3

Example: One Phosphorus (P) atom, three Hydrogen (H) atoms and one H^+ combine to form a radical called Phosphonium Ion (PH^{4+}). Since the number of charges of this PH^{4+} radical is +1, its valency is 1. In general, radicals with a positive charge are called alkaline radicals (e.g. NH^{4+}), while radicals with a negative charge are called acidic radicals (e.g. NO^{3-}).

7.2 Chemical formula of a compound

You have seen in the periodic table that each atom of an element has a specific symbol, consisting of one or two English letters. The chemical formula of a compound is a symbolic representation of the elements that make up the chemical composition of that compound. That is, here all the atoms in the molecule of a compound can be expressed through the symbols and numbers of all the atoms. For example, H_2O is one molecule of water, which contains two hydrogen (H) and one oxygen (O) atoms. So, the chemical formula of water is H_2O.

The rules for writing chemical formulas are as follows:

1) If you want to write the chemical formula of a molecule of an element, write the symbol of the atom present in that molecule, and then write the number of the atom in the subscript below the symbol of the element. For example, in a Nitrogen molecule, there are two Nitrogen atoms (N). Therefore, the symbol for Nitrogen is N_2.

Some elements do not form molecules; they are simply represented by their symbols. All metals do not form molecules. That's why, only Fe is used to denote or write Iron. Similarly, inert gases are also represented only by their symbols. For example, Helium is written as He.

2) If a compound molecule is formed by atoms of two different elements, then the symbols of the two elements (or radicals) existing in the molecule of the compound should be written side by side. Also, the subscript of the other element should be written down next to one element.

For example, as we know, Aluminum (Al) has a valency of 3, and Oxygen (O) has a valency of 2. The compound formed by these two elements is Aluminum Oxide, and its formula is Al_2O_3. Here, next to Al, the valency of O (2) is written as a subscript, and next to O, the valency of Al (3) is written as a subscript. Similarly, Calcium (Ca) has a valence of 2, and Chlorine (Cl) has a valence of 1. Therefore, according to the above rule, the formula of Calcium Chloride formed by Calcium (Ca) and Chlorine (Cl) is $CaCl_2$.

However, when the valencies of the elements or radicals in a compound are the same, it is not necessary to indicate the valency in the formula. For example, the compound Calcium Oxide, which is formed by the two elements- Calcium (Ca) with a valency of

2, and Oxygen (O) with a valency of 2, is written as CaO, not Ca_2O_2.

Again, if a molecule is associated with a radical and their valencies are known, the formula of the compound formed by them can be written according to the above rule. For example, Magnesium (Mg) is an element with a valency of 2, and Phosphate (PO_4^{3-}) is a radical with a valency of 3. Therefore, according to the rule, the formula for the compound formed by them, Magnesium Phosphate, is $Mg_3(PO_4)_2$. In this case, to avoid any confusion, the compound should be written in parentheses.

3) If the valencies of two elements are divisible by a common number, then the valencies of the two elements must be divided by the common number, and the quotients are to be written next to the two elements according to the rule. For example, the molecule, Carbon Dioxide is composed of two elements, Carbon (C) and Oxygen (O). Here, the valency of Carbon is 4, and the valency of Oxygen is 2, but we don't write it as C_2O_4. Dividing the valencies of Carbon and Oxygen by 2 gives us 2 and 1 respectively, and according to the rule, we are supposed to write 1 as a subscript for the valency of Carbon (C), and 2 as a subscript for the valency of oxygen (O). But, when writing the formula, the number 1 is not required to be written. Therefore, the chemical formula for Carbon Dioxide is CO_2.

7.3 Inert Gas and Stability

You already know that inert gases are located in Group 18 of the periodic table. The reason for the inertness or stability of inert gases is that their outermost energy level is filled with electrons. Helium has an atomic number of 2, so it has only one energy level, which is 1s. It takes only 2 electrons to fill this energy level. Those two electrons are in the outermost shell or energy level of Helium. Other inert gases have 8 electrons in their outermost energy level, filling both s and p orbitals. The electron configurations of some inert gases are shown below:

$\mathrm{He}\ (2) \rightarrow \boxed{1S^2}$

$\mathrm{Ne}\ (10) \rightarrow 1S^2\ \boxed{2s^2 2p^6}$

$\mathrm{Ar}\ (18) \rightarrow 1S^2\ 2s^2 2p^6\ \boxed{3s^2 3p^6}$

The outermost shell or outermost energy level

$\mathrm{Kr}\ (36) \rightarrow [\mathrm{Ar}]\ 3d^{10}\ 4s^2\ 4p^6$

$\mathrm{Xe}\ (54) \rightarrow [\mathrm{Kr}]\ 4d^{10}\ 5s^2\ 5p^6$

Therefore, the electron configuration of inert gases shows that Helium has 2 electrons in its outermost energy level, and other inert gases have 8 electrons. As a result, they do not need to add any more electrons to fill their outermost energy level. Thus, they achieve stability. If an element has 8 electrons in its outermost energy level, it becomes highly stable. Due to their high stability, inert gases do not lose or gain electrons from other elements. As a result, they become chemically inert or inactive.

Octet Rule: We know that since inert gases are the most stable. So, each element wants to have the electron configuration of an inert gas in its valence shell. In other words, they tend to acquire 8 electrons in their outermost energy level or valence shell. All inert gases except Helium (He) have 8 electrons in their outermost energy level. Therefore, when elements or atoms form molecules, they gain, lose, or share electrons to have 8 electrons in their valence shell, thus achieving the electron configuration of an inert gas. This tendency is known as the Octet Rule.

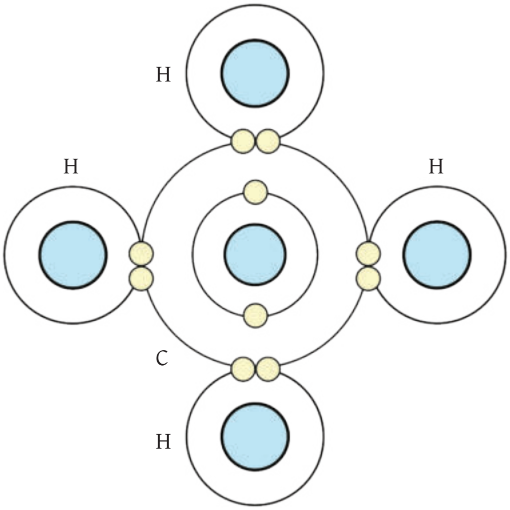


Figure 7.2: Octet rule in Methane (CH_4) molecule

Example: In the molecule, Methane (CH_4), the Carbon (C) atom has 8 electrons in its valence shell. Out of these 8 (eight) electrons, 4 are from Carbon and 4 electrons are from Hydrogen (H) atoms. This is shown in Figure 7.2.

7.4 Chemical Bond

A chemical bond is a bond between two or more atoms, molecules, or ions to form a chemical compound. This chemical bond brings together or holds the atoms in a compound. For example, two Hydrogen (H) atoms bond together to form a Hydrogen molecule (H_2). In this case, a type of force of attraction acts between the two Hydrogen atoms to form the bond, and this force of attraction is essentially the chemical bond. Therefore, the attraction by which atoms are joined together to form a molecule is called a chemical bond.

The reason for bond formation is that each element wants to be stable by achieving an electron configuration like an inert gas in its outermost energy level. Therefore, when two atoms of the same or different elements come close, they gain, lose, or share electrons in their outermost energy levels, becoming stable like an inert gas. As a result, a kind of attraction is created between the atoms, and it is this attraction that leads to the formation of chemical bonds.

7.4.1 Ionic Bond

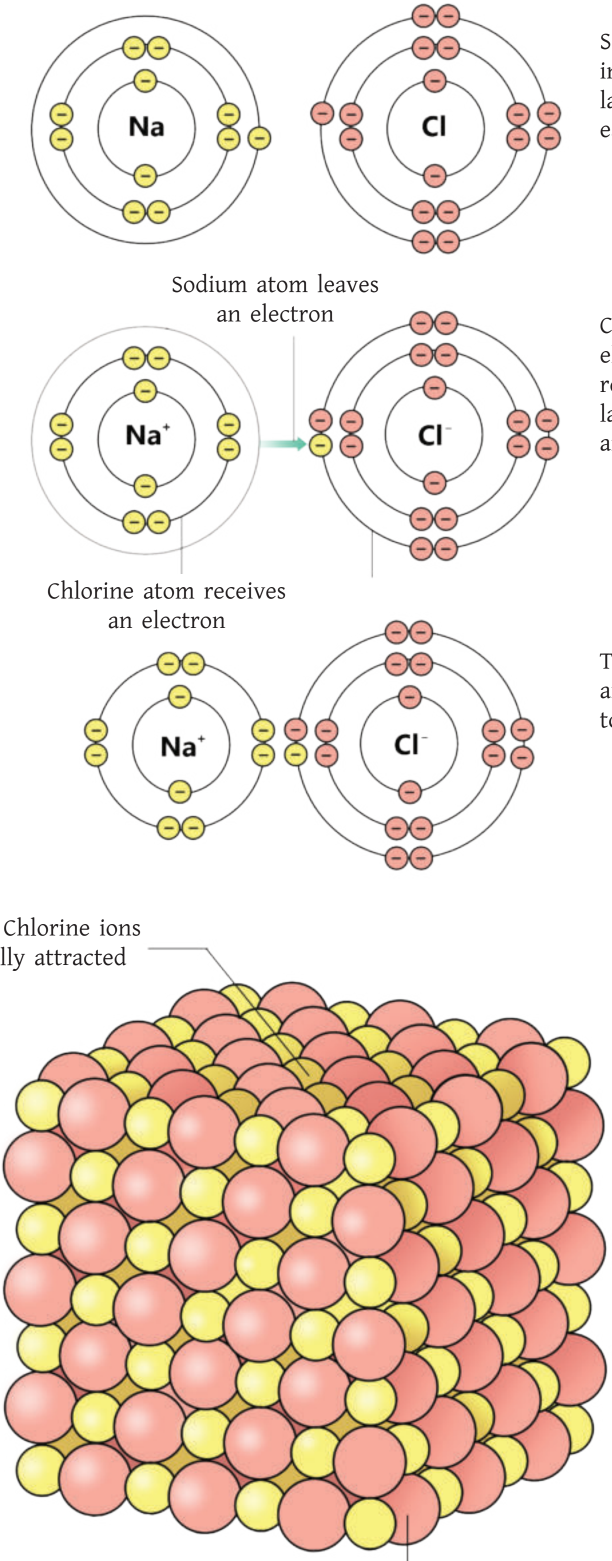
While reading the periodic table, you have noticed that metals have very low ionization energies. As a result, they can easily lose their outermost energy level electrons to become positively charged ions or cations. On the other hand, non-metals have high electron affinities, so they can easily gain electrons in their outermost energy level to become negatively charged ions or anions. The resulting cations and anions are held together by a type of electrical force of attraction that keeps them together to form bonds. This bond is called an ionic bond.

Example: Here, Sodium Chloride (NaCl) can be mentioned as an example of the bond formed between Sodium Ions (Na^+) and Chloride Ions (Cl^-). An ionic bond is present in NaCl.

As we already know Sodium (Na) loses an electron in its outermost energy level and acquires an inert gas-like electron configuration (8 electrons in its outermost energy level) to become Sodium Ion (Na^+) On the other hand, Chlorine (Cl) gains one electron into its outermost energy level and acquires an inert gas-like electron configuration (8 electrons in its outermost energy level). Thus, Chlorine transforms into a Chloride Ion (Cl^-).

Thus, Sodium Ions ($Na^{+)}$ and Chloride Ions ($Cl^{-)}$ formed in this way bond with each other through electrostatic force of attraction. Hence the bond created through electrostatic force of attraction is called an ionic bond. And, compounds in which this bond exists are called ionic compounds. In Figure 7.3, the ionic bond in Sodium Chloride (NaCl) is illustrated.

It is to be noted here that the metallic elements of groups 1 and 2 of the periodic table and the non-metallic elements of group-16 and group-17 generally form ionic bonds.



Sodium has a low ionizing potential, hence the last-shell electron leaves easily forming cation

Sodium atom leaves an electron

Chlorine has a high electron affinity, hence receives an electron to last-shell easily forming anion

Chlorine atom receives an electron

The cation and anion are electrically attracted to form Sodium Chloride

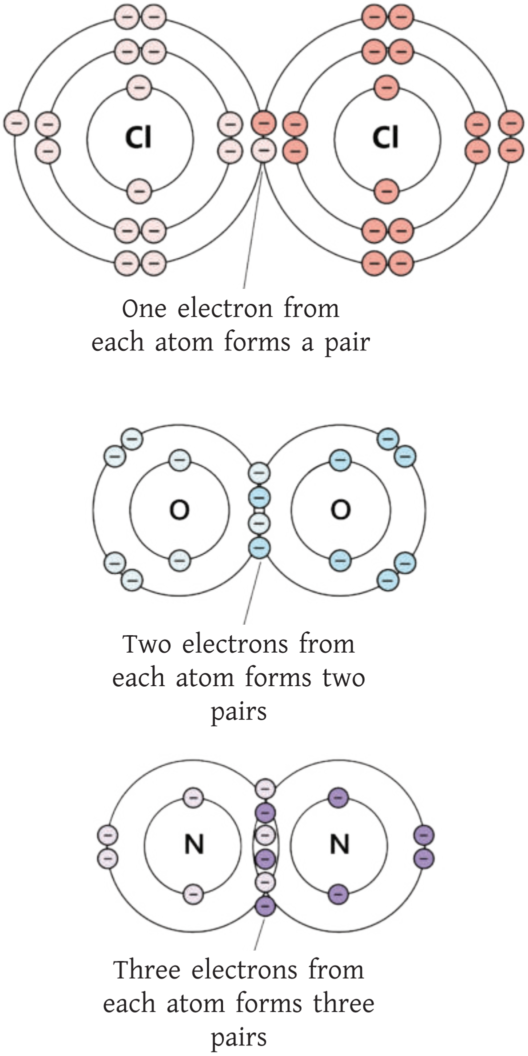
Sodium and Chlorine ions are electrically attracted

Figure 7.3: Formation of Ionic Bond of Sodium Chloride (NaCl)

7.4.2 Covalent Bond

As we know, elements with high ionization energy cannot lose electrons, and elements with low electron affinity cannot easily gain electrons. For instance, Chlorine (Cl) has seven electrons in its outermost energy level. Therefore, Chlorine won't prefer to lose 7 electrons from its energy level but rather show a tendency to gain one or two electrons. In this case, when two chlorine atoms come close to each other, one electron from the outermost shell of each chlorine atom will come together and form a pair, and both atoms will share the two electrons. This is called electron sharing.

As a result, both chlorine atoms will gain 8 (eight) electrons in their outermost energy



Covalent single bond: When an electron from each atom is shared to form a pair

Covalent double bond: When two electrons from each atom is shared to form two pairs

Covalent triple bond: When three electrons from each atom is shared to form three pairs

Figure 7.4: Covalent Bond

Water

Water (H_2O) is a covalent compound. Here, one Oxygen (O) atom is covalently bonded to two Hydrogen (H) atoms. However, because the oxygen atom is more electronegative than the hydrogen atoms, the electrons used in the covalent bond of the water molecule are slightly shifted towards the two oxygens. As a result, the oxygen atom acquires a partial negative charge. On the other hand, the hydrogen atoms acquire partial positive charges, as electrons are withdrawn from the hydrogen atoms (Figure 7.5). It is to be noted that water has two covalent bonds between oxygen and hydrogen atoms and this bond requires two electrons.

In this way, a covalent compound formed by positive and negative charges is called a polar covalent compound. Therefore, water is a polar covalent compound and a polar solvent.

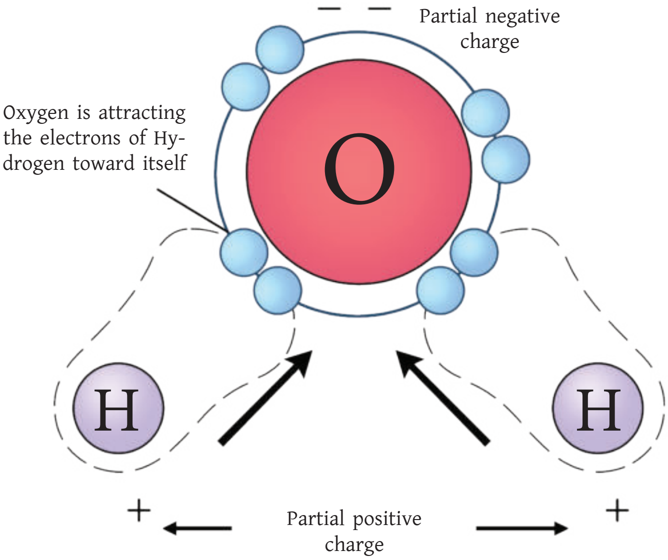


Figure 7.5 : Formation of partial positive charge and partial negative charge in water molecules

For example, when an ionic compound is added to water, the positive end of the water molecule attracts the negative end or anion of the ionic compound. Similarly, the negative end of water attracts the positive end of an ionic compound. When the value of this force of attraction is greater than the force of attraction between the cation and anion of the ionic compound, the cation and anion become separated, and surrounded by water molecules. This is how ionic compounds dissolve in water.

On the other hand, covalent compounds do not have positive and negative ends. As a result, these compounds do not experience any attraction or repulsion with the positive and negative ends of water. Therefore, covalent compounds cannot dissolve in water.

level to achieve the inert gas electron configuration. Consequently, the two chlorine atoms cannot move away from each other, and they become bound together in a kind of bond (Figure 7.4). This type of bond is called a covalent bond. A compound formed by covalent bonds is called a covalent compound.

7.4.3 Metallic Bond

We have observed the bond between a metal and another nonmetal in an ionic bond. Again, in covalent bonds, we have seen a bond between two non-metal atoms. But what happens when two metal atoms come close to each other? In fact, when two metal atoms come together, the bond that forms between their atoms is called a metallic bond. For example, metallic bonds are present in objects made of copper, iron, or aluminum; silver or gold jewelry, etc.

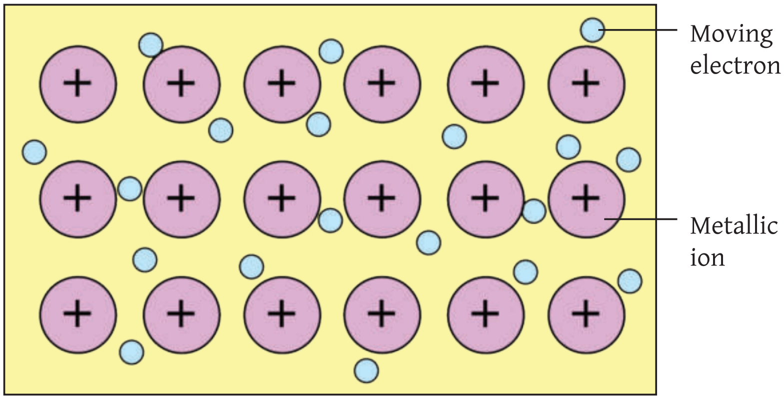


Figure 7.6: Metallic bond

We know that in the electron configuration of metallic atoms, they generally have 1, 2, or 3 electrons in their outermost energy level. These metals are larger than non-metals in the same period. As a result, the attraction between the electrons in the outermost energy level and the nucleus is weaker, and they can easily lose electrons to become positively charged ions. This positively charged ion is called the atomic core.

The electrons released from the metal atoms can move freely in the space within the atomic core. These electrons are known as delocalized electrons (Figure 7.6). In fact, these electrons do not belong to any specific atom but are shared by all the metal ions in the entire metal block. Consequently, every metal ion is attracted to these delocalized electrons by a type of stable electrostatic force. Because of this, two metal ions cannot be separated from each other and this is what causes metallic bonding. Moreover, these delocalized electrons within the metal are responsible for the electrical conductivity, thermal conductivity, ductility, and other properties of metals.

7.5 Ore, Extraction of Metals and Alloys

We use various types of metals in our daily lives. These metals are extracted from mines as ores and then collected or extracted in a profitable way to make them usable. To know about this, you need to know about ore and metal extraction.

Ore

Various metals or non-metals that are collected from all the substances that exist naturally in the ground or on the surface are known as minerals. Those minerals from which metals or non-metals can be collected or extracted in a profitable way are called ores.

Example: Galena (lead sulfide, PbS) is the ore of the metal lead (Pb). Because the metal lead (Pb) can be profitably extracted from galena. Hematite (Haematite, Fe_2O_3) is also an ore of iron because iron (Fe) can be extracted profitably from hematite.

Metal Extraction

We know that the reactivity of all metals is not the same. Some metals are less reactive, some are moderately reactive, and some are highly reactive. Because of this, the properties of different metals vary. Some metals exist in a free state, while others exist in a combined state with their respective ores. The process by which metal is extracted from its associated ore is called metal extraction.

There is no specific process to separate these metals from ores. That is why the extraction process of different metals is also different. Less reactive metals, such as Gold (Au), Platinum (Pt), and Silver (Ag), are sometimes found in nature in their pure form.

On the other hand, more reactive metals are found in nature as compounds such as oxides, sulfides, nitrates, and carbonates. These reactive metals are separated from their ores using various methods. For example, the reduction method, electrolysis method, etc. Different steps, such as crushing, grinding, purification, etc., are carried out to separate or extract metals from their ores based on their specific properties or characteristics.

Alloy

An alloy is a substance made from a mixture of two or more metals. Usually, a specific number of metals are melted together to form this mixture. The metal mixture obtained by cooling this molten mixture is called an alloy.

During the Ancient Copper Age, people used Copper (Cu) to make jewelry, a variety of tools, and machinery. Since this copper is a soft metal, it did not stay effective for long. Therefore, from ancient times, tin (Sn) was alloyed with copper (Cu), and the resulting mixture was cooled to create bronze. Bronze is a type of alloy that was used to make various tools and equipment.

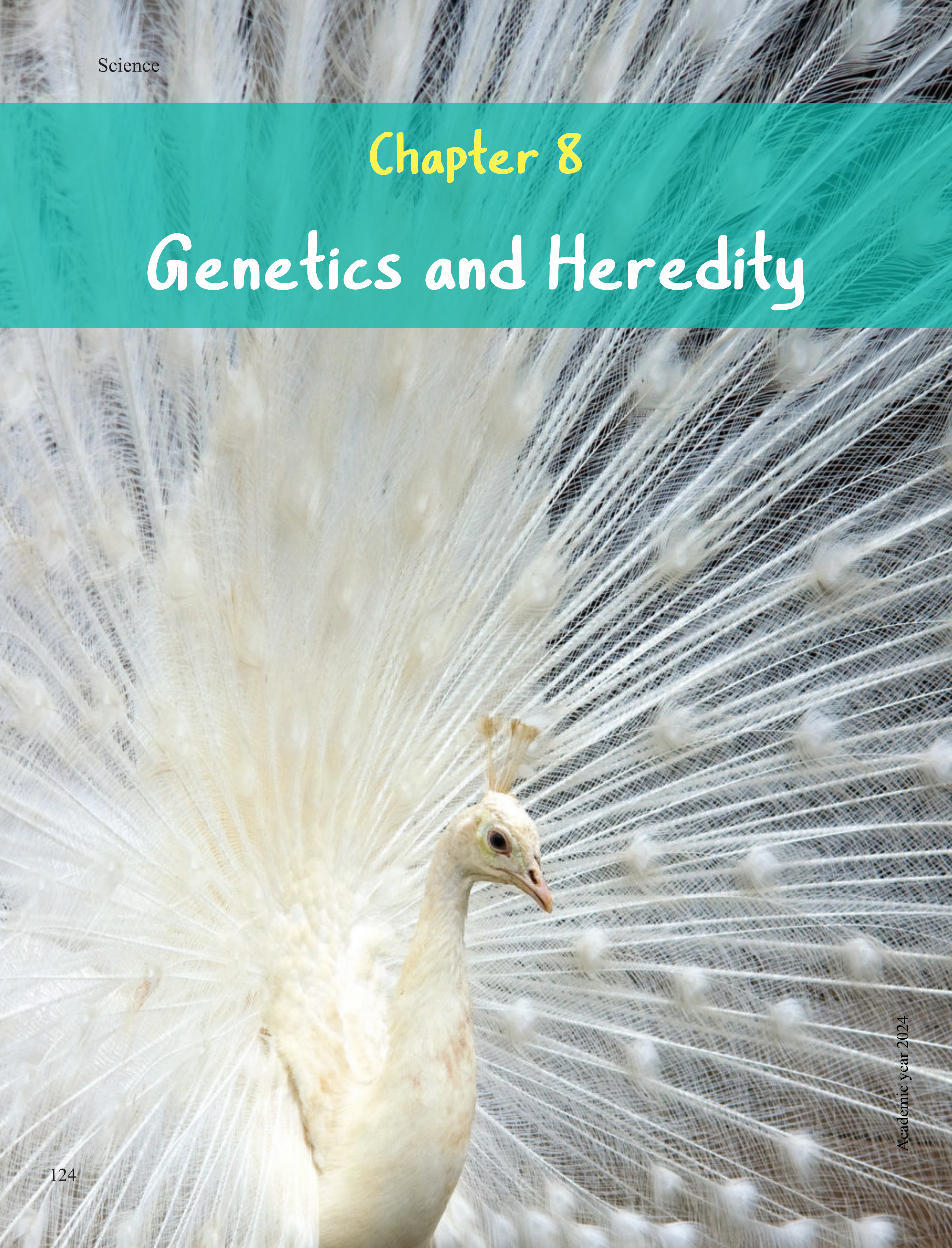
Similarly, when Carbon (C) is mixed with Iron (Fe), an alloy called steel is produced. The knives and scissors that we use in our daily lives are made of steel. Moreover, various types of agricultural machinery are also made from steel. Again, Carbon (C), Nickel (Ni), Manganese (Mn), and Chromium (Cr) are mixed with iron to make stainless steel, which is rust-free. Stainless steel is used in the manufacturing of cooking utensils, medical equipment, and surgical instruments. The table beside presents various metals and their quantities used in different well-known alloy compositions.

Several alloy metals and their quantities

Alloy	Metals and Quantity
Bronze	Copper(Cu) 80-88% Tin (Sn): 5-12%
Steel	Iron (Fe): 80-99% Carbon (C): 1-2%
Stainless steel	Iron (Fe): 72-74% Chromium (Cr): 17-19% Nickel (Ni): 7-9% It also contains very small amounts of Carbon (C), Silicon (Si) and Manganese (Mn)

Chapter 8

Genetics and Heredity



Chapter 8

Genetics and Heredity

The following topics are discussed in this chapter:

☑ What is Genetics?
☑ Relationship between Genetics and Heredity Studies
☑ Mendel, his Research and the Scientific Text of Heredity Studies
☑ Observing Manifest and Latent Traits in Organisms
☑ Selection of Traits in Organisms Using Principles of Genetics (hybridization, genetic selection)

8.1 Genetics

Our living world is full of diversity. Since ancient times, humans have been using plants and animals for their own benefit. You have already heard the name of Haripada Kapali's discovered rice Haridhan. He found an unknown species of rice in his paddy field and made seeds from there which later became a high-yielding variety. He transferred the high-yielding trait of rice to the next generation without knowing any scientific explanation. Our farmers have been coming up with such innovations from ancient times.

Figure 8.1: Gregor Johann Mendel

Reproduction is a natural and extremely important characteristic of living beings. Through reproduction, the characteristics of parents are passed on to the next generation and the organism maintains its own existence. The process of transferring the characteristics of parents from one generation to another in this way is known as heredity. The basic unit of heredity is the gene. An organism's genes are stored in the DNA of the chromosomes of a cell which you already know. Species characteristics are usually expressed and controlled by genes. The branch of science that deals with the structure, regulation, expression, and function of genes and their hereditary transmission methods and results is called Genetics. In this chapter, we will discuss this topic.

8.2 Gregor Johann Mendel and his research

Gregor Johann Mendel (1822-1884) was the first scientist to explain the scientific explanation of the inheritance of traits of living beings through heredity. This scientist (Figure 8.1) was a present-day Czech citizen and a clergyman. For a long seven years, he examined various characteristics of pea plants and expressed his views on heredity. However, Mendel's published essay remained unnoticed by the public until after his death. Sixteen years after Mendel's death, three scientists, Hugo de Vries, Carl Correns, and Erich von Tschermak, independently discovered the results of Mendel's research. It is surprising that these scientists learned about Mendel's research after completing all their investigations. In this way, the discovery and publication of the basic principles of heredity through Mendel's research paved the way for Genetics in Biology. For this reason, Mendel is called the Father of Genetics.

Mendel's Research and Selection of Traits in Organisms

Johann Gregor Mendel was a clergyman by profession but he was essentially a keen scientist. For the purpose of studying heredity, he selected pea plants in his monastery garden and carried out hybridization through controlled pollination. He began his research in 1856. There were several reasons behind Mendel's choice of pea plants for his experiments. For example, (1) pea plants are annuals and produce results of hybridization within a short time, (2) they are bisexual plants and reproduce sexually by self-pollination (3) their flowers are large and easy to pollinate, (4) they have no chance of cross-fertilization due to the way the corolla surrounds the stamens and pistils, and (5) they have several contrasting characteristics that make it easy to identify the clear expression of certain traits in hybridization. (6) The offspring created by hybridization can be fertile and can regularly increase the population of the species.

Mendel collected seeds of 34 types of pea plants from various sources, and in the garden of the monastery checked the purity of specific characteristics of each type of seed for almost a year. After the test, he selected 14 pea plants with opposite traits for

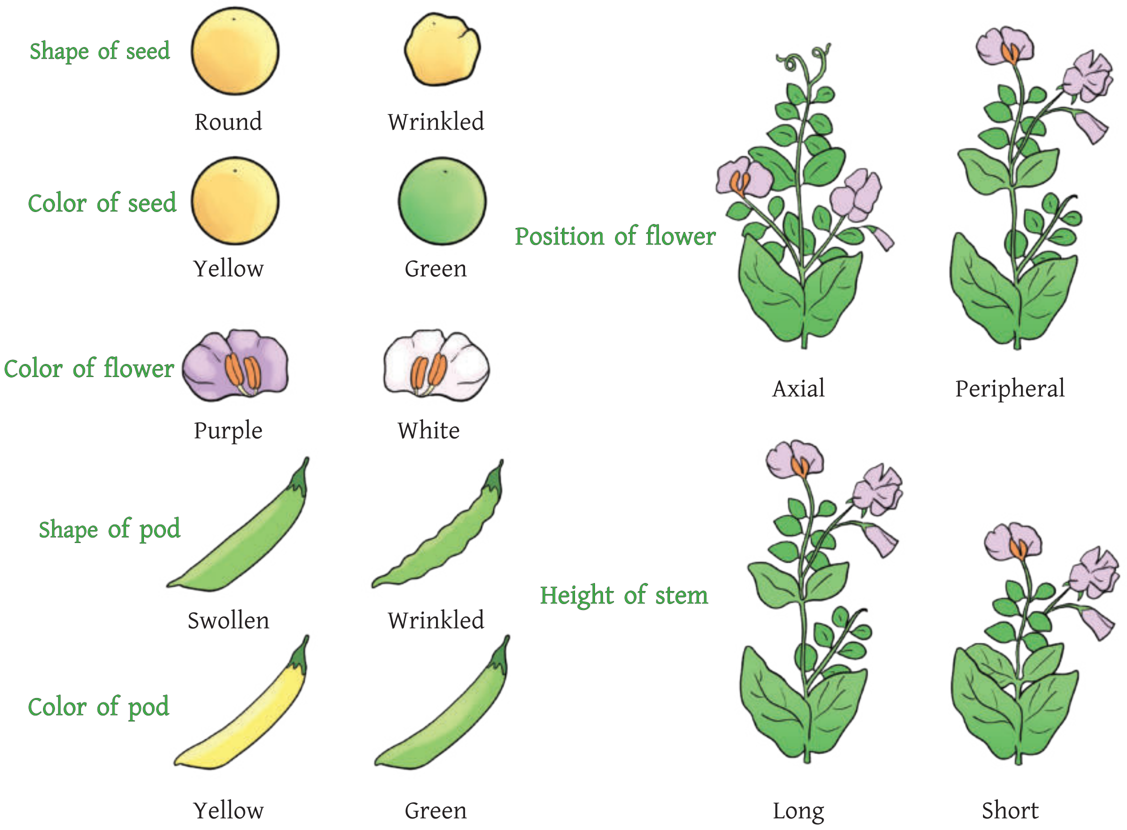


Figure 8.2: Seven different traits of pea plants

each of the seven characteristics: length of stem, position of flower, colour of flower, colour of fruit, shape of fruit, colour of seed and shape of seed. That is, for the length of the stem, the two opposite traits are long and short, for the color of the flower the two opposite traits are white and purple, and for the shape of the seed the two opposite traits are round and wrinkled (Figure 8.2). In the beginning, Mendel started his experiment with pea plants that had opposite traits of height and width. Since this was just one characteristic of the pea plant, i.e., the length of stem, it is called a monohybrid cross (mono means one).

Before starting the experiment, he ensured the purity of the pea plants. Then he cross-pollinated a purebred tall plant with a purebred short plant. He placed pollen from the tall plant onto the stigma of the short plant. Even though the tall and short plants were cross-pollinated, only tall plants were produced from all the seeds. These plants were called the first filial generation or F_1 generation. He then cross-pollinated the F_1 plants among themselves. The second filial generation or F_2 generation had a 3:1 ratio of tall to short plants. That is, inside the tall plants of F_1 generation, traits of short plants were somehow hidden, which came out during the second hybridization.

Later Mendel examined pea plants with two characteristics – seed color (yellow or green) and seed shape (round or wrinkled). Due to the examination of two different traits, it is called a dihybrid cross (di meaning two). One parent with pure yellow color and round seeds was crossed with another parent with pure green color and wrinkled seeds. In the F_1 generation, all offspring had yellow color and round seeds. When these F_1 individuals were crossed among themselves in the F_2 generation, the observed ratio was 9 yellow-round, 3 yellow-wrinkled, 3 green-round, and 1 green-wrinkled seed-producing plants among the 16 offspring (as seen in the diagram).

At first glance, Mendel's observations may seem quite complex to you, but using Mendel's two principles, you can easily explain these observations. Before that, you need to familiarize yourself with two aspects related to visible and inherent characteristics in living organisms.

8.3 Observing the dominant and dormant/recessive characteristics in living organisms

One important aspect of Mendel's research was the observation of dominant and dormant characteristics in living organisms. You've learned that in the genetic makeup of living organisms, traits are transmitted from generation to generation through genes at the primary level. When examining the color of flowers, Mendel noticed that pea plants did not have an intermediate color; they were either wite or purple. This means that a specific gene determines the color of a flower. Each individual plant has pairs of corresponding genes, one inherited from the father and the other from the mother. These pairs of corresponding genes are called alleles. In a diploid organism, the two alleles can be the same or different. If the alleles are the same, it is called homozygous, and if they are different, it is called heterozygous. The alleles of a specific gene in an organism are referred to as its genotype, while the observable external characteristics are called its phenotype.

In heterozygous organisms, the characteristic expressed by the allele that is dominant (i.e., more prominent in the phenotype) is known as the dominant gene. In Mendel's experiments with tall and short plants, the F_1 generation plants were all tall because the allele for the tall trait was dominant. On the other hand, the allele that does not express itself in the external characteristics (or phenotype) of the organism is called the recessive gene. In the example given earlier, it was the gene for short plants.

Mendel's Laws

Mendel himself did not advocate any theory; he presented the principles of segregation and independent assortment only through observational and statistical explanations in his research papers. In later years, Carl Correns, who had published Mendel's experiments, presented Mendel's discoveries as two fundamental principles of heredity. Since these principles were based on Mendel's research, they became known as Mendel's laws. It is worth noting that during Mendel's time, the term 'factor' was used to describe what we now know as genes in modern genetics, because at that time modern genetics was not yet in vogue. Below are the descriptions of Mendel's two laws.

Mendel's First Law or Law of Segregation

In hybrid organisms the opposite traits (genes) are not mixed or changed, they stay side by side and separate from each other during the formation of gamete.

Modern Genetic Explanation:

Now, using this principle, we can explain Mendel's 3:1 ratio in the segregation of tall and short traits in the F_2 generation.

Let's assume that T is the responsible gene for tall pea plants, and t is the gene for short pea plants. Therefore, pure tall pea plants will have alleles TT, and pure short pea plants will have alleles tt. Since both alleles are identical, these are homozygous. Let's assume as before that F_1 represents the first generation and F_2 the second generation,

When a pure tall pea plant (TT) is crossbred with a pure short pea plant (tt), during the formation of gametes in the offspring plants, the T allele from the tall plant combines with the t allele from the short plant, resulting in Tt alleles in the offspring. No other combinations are possible. Since the T allele is dominant, the F_1 generation plants will all be tall. Although both alleles stay together for a long time, they do not mix but segregate independently, maintaining their individuality.

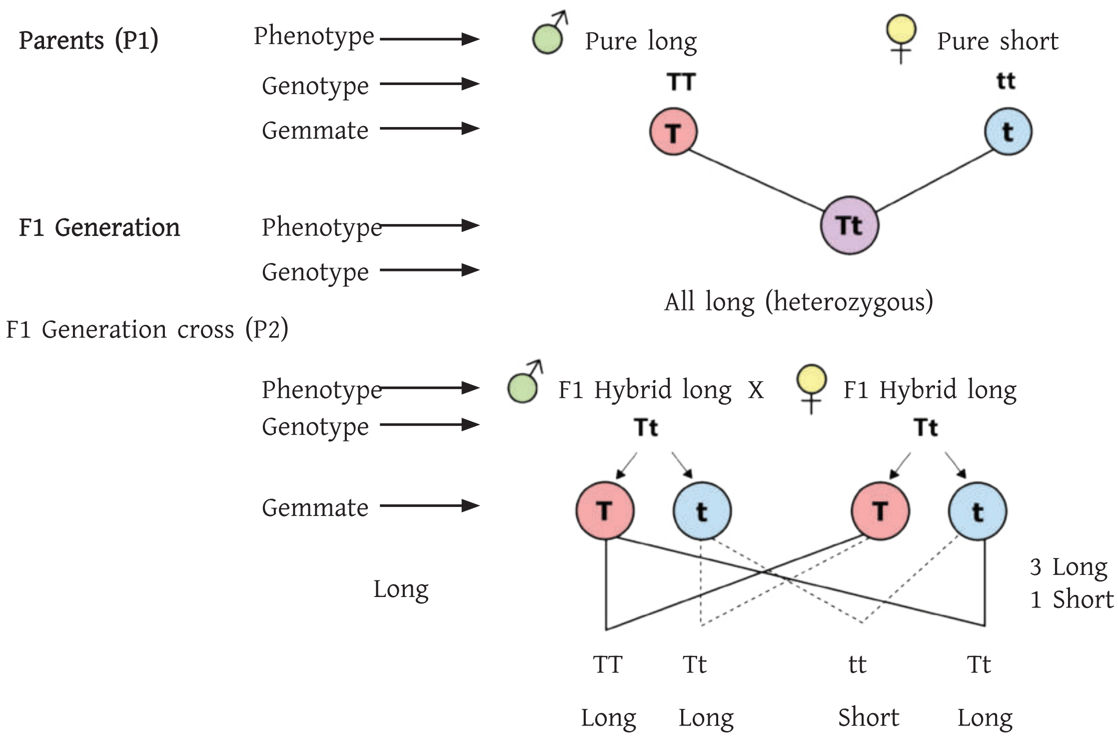


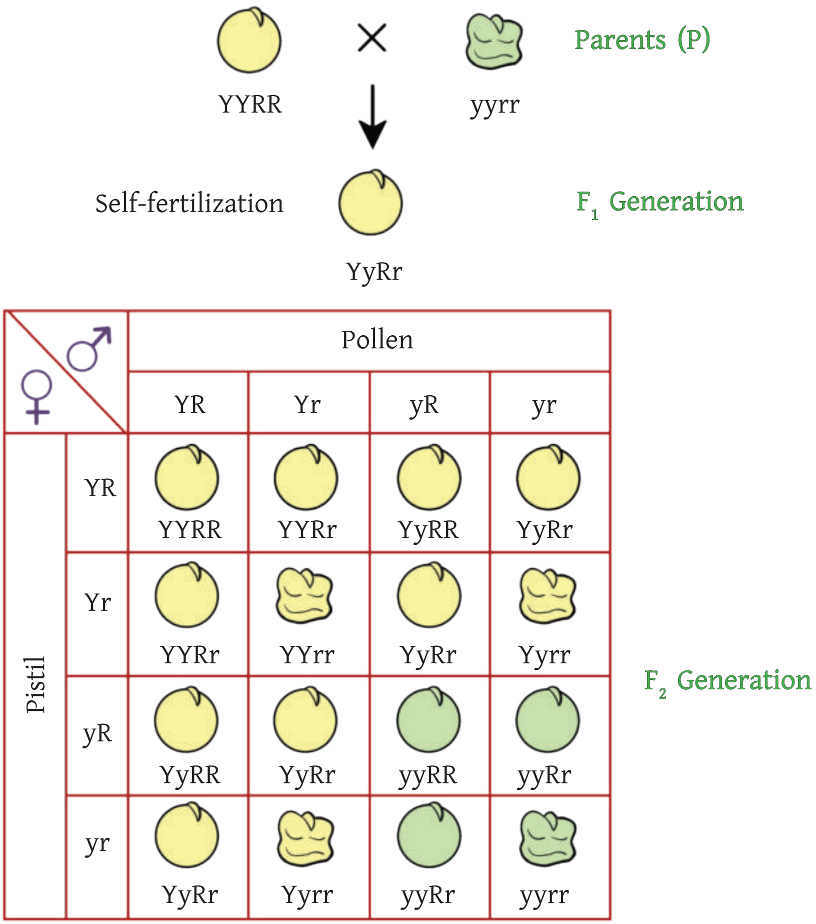
Figure 8.3: Two Generations in Monohybrid Cross

When the F_1 plants self-pollinate, the possible genotypes in the F_2 generation will be TT, Tt, tT, and tt (see Figure 8.3). Due to the dominance of the T allele, the plants with genotypes TT, Tt, and tT will be tall, while the plant with genotype tt will be short. In other words, based on the expressed traits or phenotypes, the expected ratio of tall to short plants in the F_2 generation will be 3:1.

When the genotype of members of the F_2 generation is analyzed, it is observed that among the 3 visible (tall) plants, one is homozygous (TT), and the other two are heterozygous (Tt, tT). The characteristic trait (t) that was not expressed in the F_1 generation is expressed in the F_2 generation as homozygotes (tt). Similarly, the pure homozygote (TT) that was absent in the F_1 generation is also present in the F_2 generation. This provides evidence that even though T and t were present together in the first F_1 generation, their independent identities did not get lost, only reappearing during gamete formation.

Mendel's Second Law or Law of Independent Assortment

When crossbreeding plants with two or more contrasting traits, in the first generation (F_1), only the dominant traits will be expressed. However, during the formation of reproductive cells, the traits will segregate and independently assort from each other, entering different gametes.



♀ \ ♂	YR	Yr	yR	yr
YR	YYRR	YYRr	YyRR	YyRr
Yr	YYRr	YYrr	YyRr	Yyrr
yR	YyRR	YyRr	yyRR	yyRr
yr	YyRr	Yyrr	yyRr	yyrr

Figure 8.4: Two Generations in Dihybrid Cross

Modern Genetic Explanation

To demonstrate this principle, Mendel performed a cross between plants with two pairs of contrasting traits. Two purebred (homozygous) pea plants were selected, one with round and yellow seeds and the other with wrinkled and green seeds. Assuming Y represents the allele for the yellow trait (expressed with a capital letter), y for the green trait (expressed with a lowercase letter), R for the round seed trait, and r for the wrinkled seed trait, and as before, the first generation is F_1, and the second generation F_2.

According to Mendel, each trait is determined by two genes. Therefore, for each gene, there are two alleles responsible. Thus, for the yellow (YY) and round (RR) traits, the genotype of the plant will be YYRR, and for the green (yy) and wrinkled (rr) traits, the genotype of the plant will be yyrr. As a result, the offspring of two purebred plants with different traits, characterized by the genotypes YYRR and yyrr, will be heterozygous for both traits (YyRr) in the F_1 generation. Since yellow (Y) and round (R) are dominant alleles over green (y) and wrinkled (r), all plants in the F_1 generation will exhibit the dominant traits - round and yellow seeds.

During the second cross, when the F_1 hybrid with the genotype YyRr is used for reproduction, it can produce gametes with combinations of YR, Yr, yR, and yr. Through their combination in fertilization, 16 different genotypes can be formed (Figure 8.4). Among these, there are four types of phenotypes or phenotypic ratios possible: round-yellow, wrinkled-yellow, round-green, and wrinkled-green. Since round (R) and yellow (Y) are dominant alleles over wrinkled (r) and green (y), we observe within the 16 genotypes that the phenotypes are round-yellow 9 times, wrinkled-yellow 3 times, round-green 3 times, and wrinkled-green 1 time. Therefore, their ratio is 9:3:3:1, exactly as Mendel had observed.

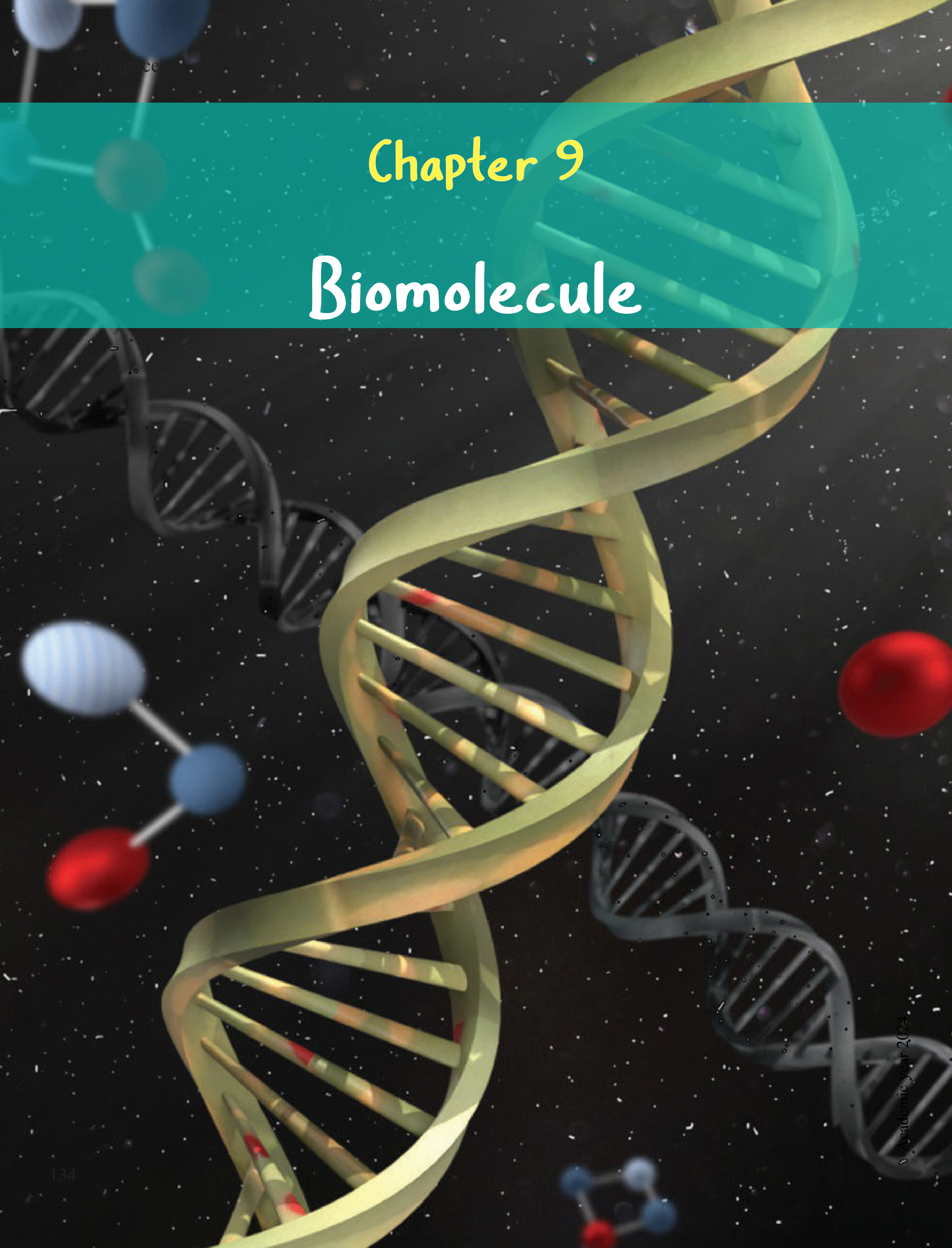
8.4 The Relationship between Genetics and Heredity Studies

You already know that heredity refers to the transmission of genetic traits from parents to offspring over generations. For this reason, children have many similarities with their parents. In the field of genetics, various topics related to heredity are discussed based on scientific principles. Scientist William Bateson first used the term "Genetics" in 1906, derived from the Greek word "Genno," meaning to give birth in English.

Gregor Johann Mendel, based on the results of his hybridization experiments, understood that each characteristic of any organism is controlled by a unit. This unit is located in pairs in the organism's body and gets separated during the formation of haploid gametes, with each unit being halved in number. However, Mendel was unaware of what this unit was, where it was located in the gamete, and how these units controlled the inheritance of traits through generations. After the rediscovery of the laws of Mendel in 1900, similarities were observed between chromosomes and Mendel's units. Each chromosome has a unique shape and length, and they exist in pairs in the body cells. One member of a pair comes from the father, and the other comes from the mother. In humans, there are 46 chromosomes in body cells, with 23 coming from the father and the remaining 23 from the mother. Only sperm and egg cells carry 23 chromosomes, and during fertilization, the fusion of these two cells results in the formation.

Chapter 9

Biomolecule



Chapter 9

Biomolecule

The following topics are discussed in this chapter:

☑ What is Organic molecule
☑ Biomolecules
☑ Major organic molecules
☑ carbohydrates
☑ Nucleic acid
☑ protein
☑ lipids
☑ Interrelationships of organisms

The coexistence of plants and animals forms our beautiful biosphere. You must want to know where they all came from. Are all animals created from the same material or are there any differences in origin between plants and animals? Again, humans can eat green vegetables, but cannot digest grass. But the main food of cows is grass. That means all plants and animals must have some structural differences that set them apart. Generally, many molecules are directly involved in the formation of living organisms, they are called biomolecules. In this chapter we will discuss organic molecules.

9.1 Biomolecule

Living cells are made up of numerous molecules. These molecules include small molecules and large molecules which are collectively known as biomolecules. These biomolecules are generally composed of more than 25 elements, of which six elements are considered as common components of biomolecules. These are carbon (C), hydrogen (H), nitrogen (N), oxygen (0), phosphorus (P) and sulfur (S). The abbreviation of the English spelling of all these basic substances is CHNOPS. As you have already read in detail about cells, all cells are made of these organic molecules. Carbon is the most important atom among the six atoms of CHNOPS in terms of the structure of the living

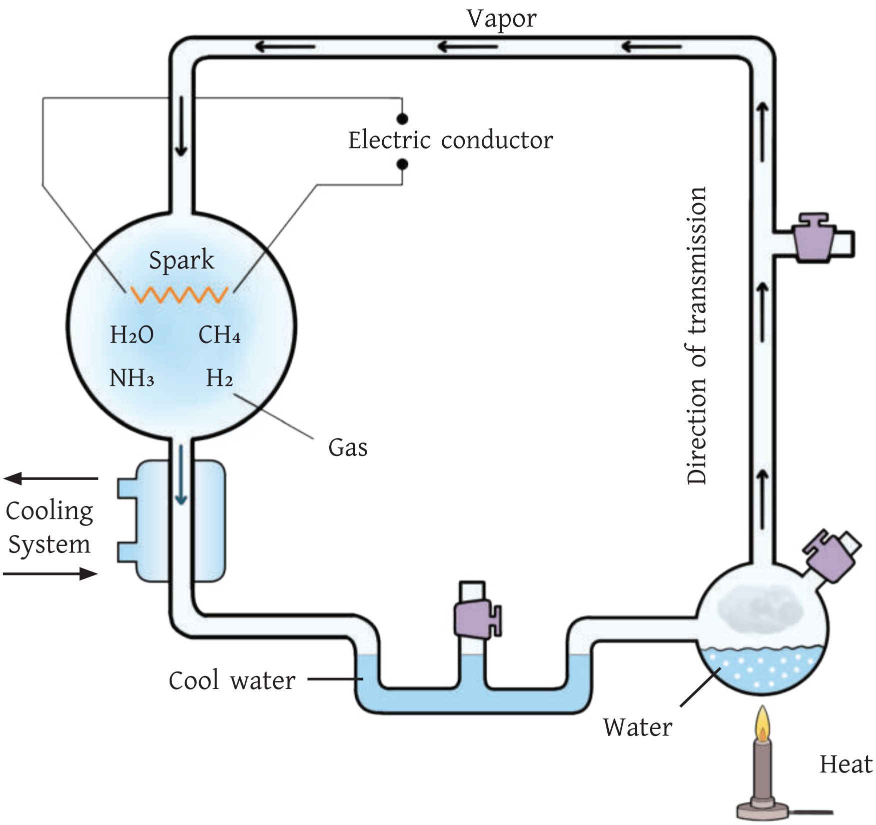
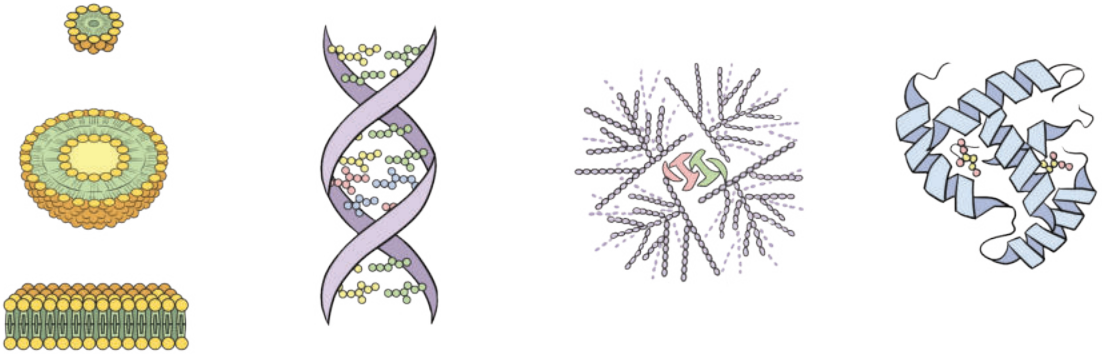


Figure 9.1. Miller-Urey's experiments on the synthesis of organic molecules from inorganic molecules.

world. That is why it is said that carbon is the basis of life on earth

Organisms are made up of four types of biochemical substances namely carbohydrates, proteins, nucleic acids and lipids. Without these two organic chemicals, proteins and nucleic acids, living things are not made. From this it can be assumed that organic molecules were formed from the beginning of creation and as a result of various chemical reactions they were combined to form the first cells. Scientists believe that lightning or frequent electrical storms, and strong solar radiation accelerated some chemical reaction that led to the formation of these organic molecules from inorganic molecules on primeval Earth. To prove this idea, in 1953, scientists Stanley Miller and Harold Urey created an artificial model of an early Earth in the laboratory (Figure 9.1). Where in a completely enclosed system, a mixture of water, methane, ammonia and hydrogen was constantly circulating on the ancient Earth. There were electrical discharges simulating the lightning of that time. After a week, they saw the synthesis



Lipid Nucleic acid Carbohydrate Protein

Figure 9.2. Four types of organic molecules

of organic molecules called amino acids, that is, they proved that it is possible to create organic molecules from inorganic molecules in the natural environment.

The basic components of living organisms, carbohydrates, proteins, nucleic acids and lipids are made up of biochemical substances called biopolymers of cells. For example, carbohydrates are simple sugars, proteins are amino acids, nucleic acids are mononucleotides, and lipids are biological polymers of fatty acids. In this chapter we will discuss these four types of biomolecules (Figure 9.2).

9.2 Carbohydrates

Carbohydrates are an important structural, storage and energy source of the body. Carbohydrates are complex natural organic compounds that mainly consist of carbon (C), hydrogen (O) and oxygen (O) elements. Carbohydrates contain carbon, hydrogen and oxygen atoms in the ratio of 1:2:1

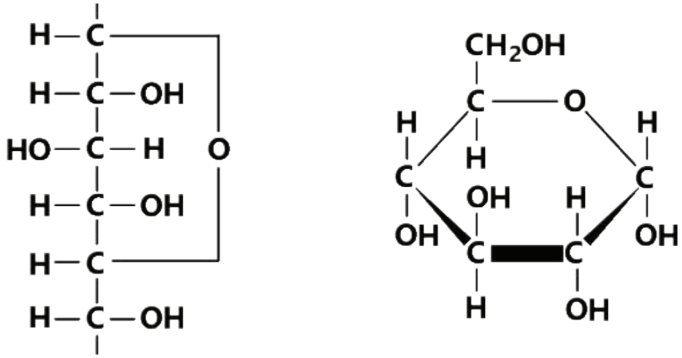
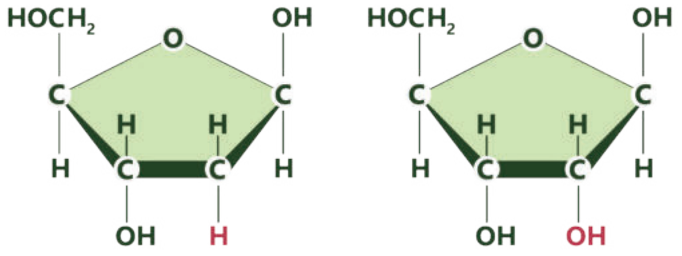


Figure 9.3: C_2H_2O of glucose, type molecule: CHO

Carbohydrates are produced from carbon dioxide and water in the presence of sunlight and with the help of chlorophyll in the process of photosynthesis in the green part. A large part of our daily diet consists of sugars or carbohydrates. Carbohydrates are one of the main 7 nutrients (water, carbohydrates, fiber, fat, protein, vitamins and minerals) related to nutrition in our body. Carbohydrates provide our body with necessary energy and if present in excess, it gets stored in the body as fat. After the breakdown of sugar in the body, it is divided into various small sugar molecules and when it reaches the smallest part in stages, it is absorbed in various parts of the body.

You all know that carbohydrates can be classified in several ways,. A type of carbohydrate that is sweet in taste, granular and soluble in water is known as sugar. Glucose (Figure 9.3) is an example of a sugar. The other is starch, which is not sweet, granular and insoluble in water. Rice, flour, potato etc. from our familiar plants contain large amounts of starch.



2- Deoxyribose Ribose

Figure 9.4. Two types of pentose sugars

Carbohydrates can be divided into several categories on the basis of molecular structure, molecular weight and chemical religion. Monosaccharides are the smallest and simplest units among them. It serves as the building block of other complex carbohydrates. Their common symbol is $C_nH_{2n}O_n$. If the number of carbon atoms in their molecule is 5, it is called a pentose sugar. Figure 9.4 shows two pentose sugar molecules, one a deoxyribose sugar and the other a ribose sugar. Ribose and deoxyribose sugars are structurally similar but the only difference is that one carbon of deoxyribose sugar does not have oxygen.

As you read about nucleic acids, you will see that this pentose sugar is one of the main components of nucleic acid, a very important biological molecule in life

Physiological role of carbohydrates:

1. Carbohydrates are the main source of energy in the body. Carbohydrates are broken down into glucose when ingested as food, and most cells use this glucose for energy or

store it as glycogen in the liver and muscles for future use.

2. Glucose from carbohydrates serves as the sole energy supplier for the brain and central nervous system.

3. Carbohydrates provide energy to the body's muscles. Glycogen is one of the heart's main sources of energy.

4. Carbohydrates ensure that protein is not diverted from its intended vital physiological function and converted into energy.

5. Complex carbohydrates such as indigestible carbohydrates and cellulose, pectin help in the formation and elimination of stool.

6. Adequate fiber-rich complex carbohydrates in the diet regulate blood glucose levels.

9.3 Nucleic acid

Nucleic acids are actually large organic molecules, which are essential for every living organism. The organic molecules present in the chromosomes and ribosomes of the nucleus are called nucleic acids. In addition to the nucleus and ribosomes, mitochondria and plastids contain nucleic acids. Nucleic acid A type of organic molecule composed of a pentose sugar, a nitrogenous base or base, and phosphoric acid, which controls all activities of an organism, including the process of heredity.

There are two types of nucleic acids, DNA and RNA.

9.3.1 DNA

DNA or de-oxyribonucleic acid is the most important permanent chemical molecule in the cell. It contains and controls all the biological functions and hereditary characteristics of the cell or the organism as a whole. All living cells except a few viruses contain DNA. Chromosomes are made up of DNA and some proteins. DNA is attached to these proteins to form long threads, known as chromosomes. DNA can also be found in mitochondria and plastids. The amount of DNA in the cells of certain species is fixed. DNA is a type of chemical organic compound whose molecules are made up of many small molecules called nucleotides. Figure 9.5 shows the structure of DNA.

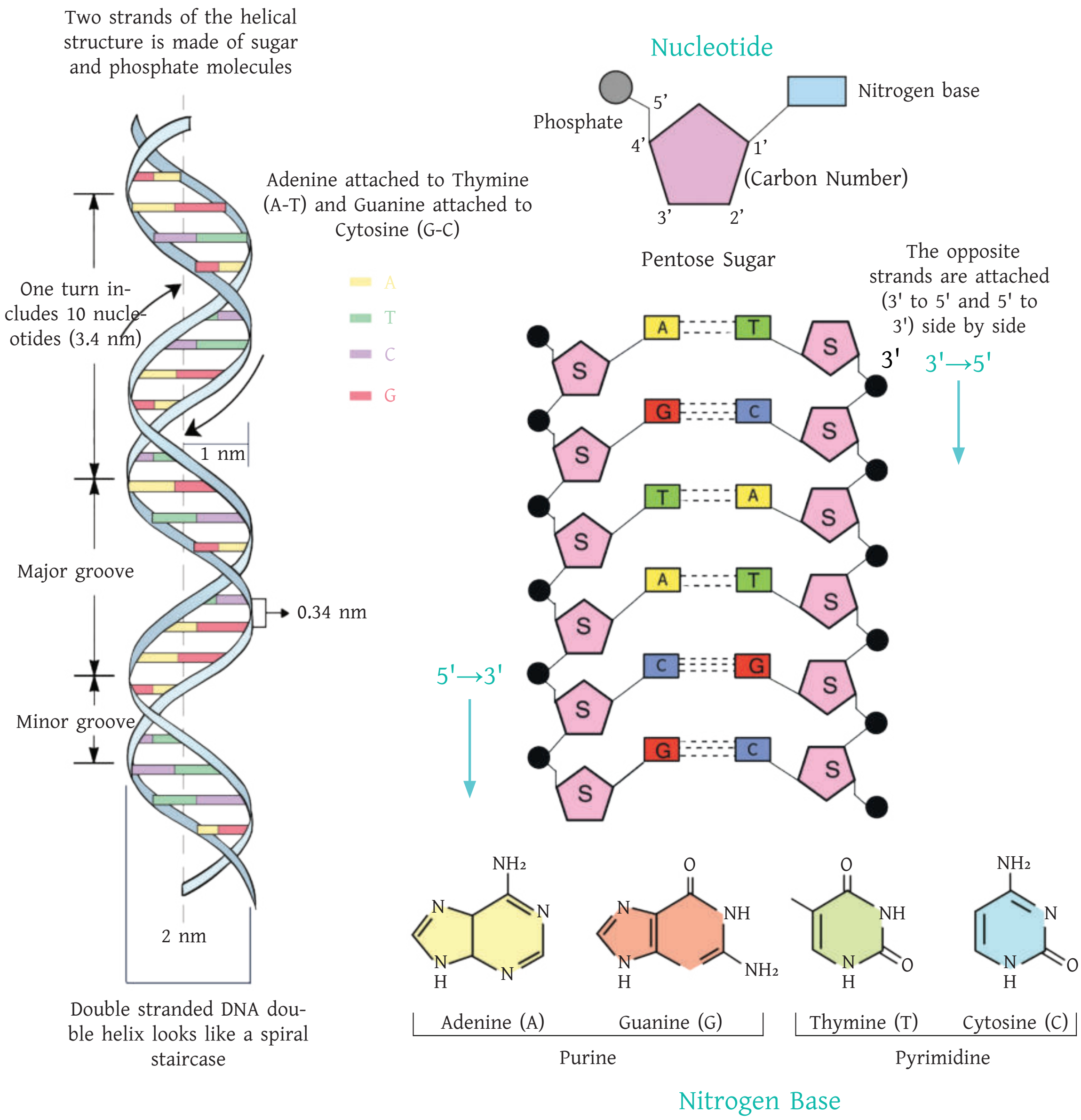


Figure 9.5 The structure of DNA.

You can see in the diagram that each nucleotide is made up of a pentose sugar, a phosphate group and a nitrogenous base or base. Nucleic acids contain two types of pentose sugars. One of these is ribose sugar and the other is deoxyribose sugar. The pentose sugar in DNA is the deoxyribose sugar. DNA has four nitrogenous bases which are adenine, guanine, cytosine and thymine.

DNA is a spiral structure of numerous nucleotides with two strands, one of which is a strand complementary to the other. Two DNA strands or strands of a DNA molecule twist around each other to form a spiral shape called a double helix structure. Scientists James Watson and Francis Crick proposed the DNA double helix model of the physical and chemical structure of DNA in 1953, which earned them the Nobel Prize in 1963.

Functions of DNA:

☑ Possesses and controls all the characteristics of the organism.

☑ Acts as a structural component of chromosomes.

☑ Acts as the molecular basis of heredity.

☑ Life acts as a regulator of all physiological and biological functions.

☑ When the structure of DNA is disturbed, it repairs itself.

☑ It plays a key role in evolution by creating variation through mutation.

9.3.2 RNA

RNA or ribonucleic acid exists in the cytoplasm of cells free or associated with ribosomes. The main difference between RNA and DNA is that it is not double-stranded like DNA, but a single chain of nucleotides (Figure 9.6).

In the case of some viruses (eg Covid virus or SARS-Cov-2.) DNA is missing. That is, all viruses that are not made up of DNA have RNA as their nucleic acid. In these cases RNA acts as the genetic material.

RNA is mainly of three types. Ribosomal RNA (Ribosomal RNA or rRNA), messenger RNA (Messenger RNA or mRNA), and transfer RNA (Transfer RNA or tRNA). We get an idea of the function of these RNAs when we read about the synthesis or structure of proteins

Function of RNA :

☑ The main function of RNA is to synthesize proteins.

☑ Carrying messages from DNA to ribosomes.

☑ Carrying hereditary characteristics.

9.4 Protein

Protein is one of the most important biochemical substances and large complex organic molecules in living organisms. Gerrit Müller first used the term protein in 1838. Different types of proteins are made inside a cell, which play many important roles in the body. Biological reactions in cells are controlled by a variety of enzymes, antibodies, and hormones—all of which are proteins. It is also essential for the structure, function and regulation of body tissues and organs. Since more than one amino acid is arranged to form a protein, before knowing about protein, we need to know a little about amino acid.

Amino Acid 20 different types of amino acids (Figure 9.7) combine in different arrangements to form the primary structure of a protein. Primarily proteins are long chains made of amino acids. The primary structure of each protein differs from each other due to differences in the arrangement of amino acids.

You already know about the arrangement of nucleotides in DNA (ATGC). The arrangement of amino acids depends on the arrangement of these nucleotides. Usually three bases combine to form a signal for the addition of an amino acid. The carboxyl group of one amino acid joins with the alpha amino group of the next amino acid to form a peptide bond. Thus a polypeptide chain or protein is formed as a result of the joining of numerous amino acids.

It should be noted here that out of 20 amino acids, 11 can be synthesized in the human body, the remaining 9 must be obtained from food.

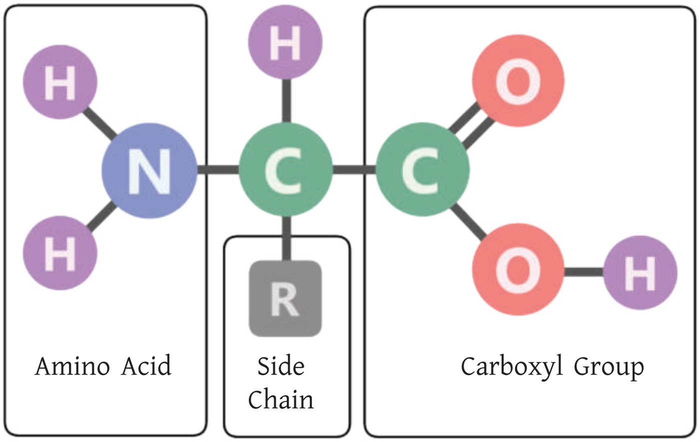


Figure 9.7 : Structure of Amino Acid

Protein synthesis

Figure 9.8 shows the process of protein synthesis. A T nucleotide is converted to a U when making RNA from DNA. Three nucleotides are linked by one amino acid in a polypeptide chain.

Functions of Protein

(1) Food containing protein provides energy to our body and helps in physical growth and maintenanc

(2) Helps in numerous biochemical reactions inside and outside the cell.

(3) Some protein hormones are chemical messengers, they help in communication between body tissues and organs.

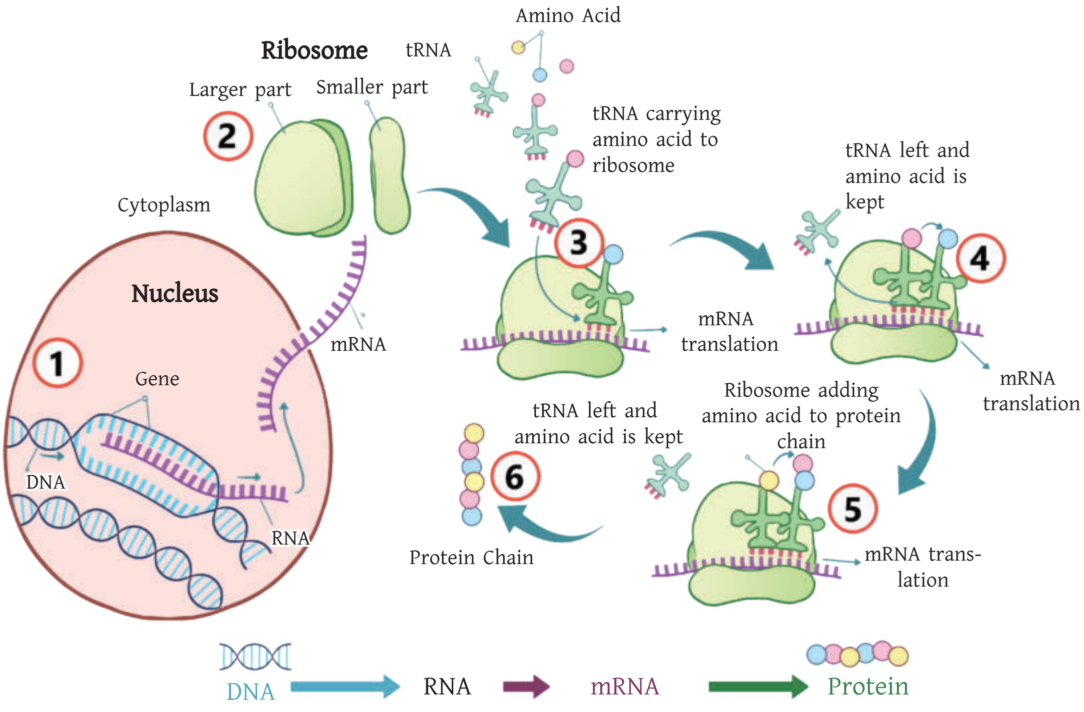


Figure 9.8: Different steps of protein synthesis

(4) Proteins play an important role in regulating and maintaining the balance of acid and alkali concentrations in the blood and other body fluids.

(5) Proteins help our body produce antibodies to fight infections from foreign microorganisms.

9.5 lipids

Lipid refers to fatty substances composed of carbon, hydrogen and oxygen. Lipids are important biochemical substances in plant and animal bodies. It plays important roles in cell structure, energy storage, thermoregulation and intercellular communication. In 1940 German scientist Bloor first used the term lipid. Lipids are generally found in animal and plant oils and fats. It is abundant in various parts of plant body especially fruits and seeds.

Lipids are almost insoluble in water but soluble in solvents such as ether, alcohol, benzene, chloroform, acetone, petroleum etc. Lipid is colorless, tasteless and odorless, has no specific melting point, its melting point increases with increasing molecular weight. The relative importance of lipids is less than water, lipids float on water because they are lighter than water. At normal temperatures, some lipids are liquid and some lipids are solid. Lipids that are in solid form are called fats and lipids that are in liquid form are called oils.

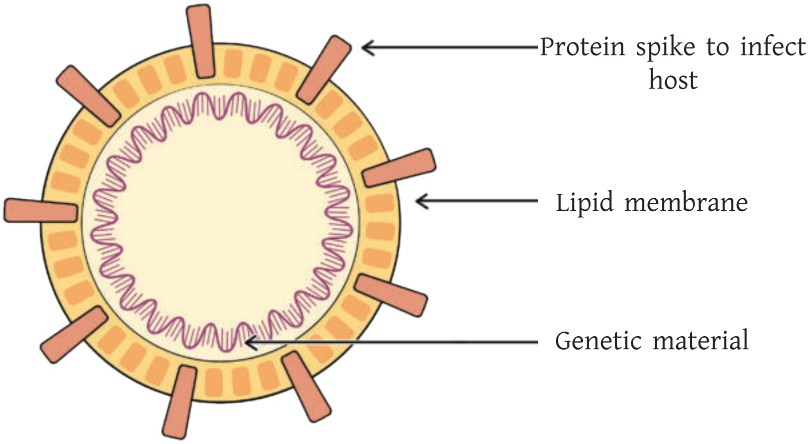


Figure 9.9. Corona virus

Since lipids are hydrophobic, they act as cell membranes. Due to the lipid membrane of the corona virus (Figure 9.9), which is responsible for the worldwide corona epidemic, it was possible to inactivate the virus by penetrating the membrane very easily with soap, disinfectant or some alcohol. That's why during the covid epidemic, a lot of importance was given to hand washing with soap or sanitizing hands for health protection.

Functions of Lipids:

(1) Lipids combine with proteins to form lipoproteins, which are involved in energy production processes.

(2) A type of lipid called phospholipids acts as a component in various membrane structures.

(3) A type of lipid plays a special role in the photosynthesis process of plants.

(4) Lipids such as fats and oils are stored in the plant body as food. of various oilseeds. Lipids are ingested during germination.

(5) Waxy lipids form a layer on the outer coat of leaves to prevent excessive transpiration and it also protects the plant from various insect attacks.

9.6 Interrelationships of Biomolecules

You already know that the major biomolecules of living organisms are carbohydrates, nucleic acids, proteins, and lipids. Each of these biomolecules is related to each other in structure and in carrying out biological functions. Below is a brief discussion on this topic

Carbohydrates and Nucleic Acids: We have learned in the discussion that all living organisms. DNA controls physiological and biological functions, one example of which is cell division. This nucleic acid called DNA contains the genetic information of an organism. If you look at the structure of DNA, you will see that it is made up of a peltose sugar called deoxyribose, which is a carbohydrate.

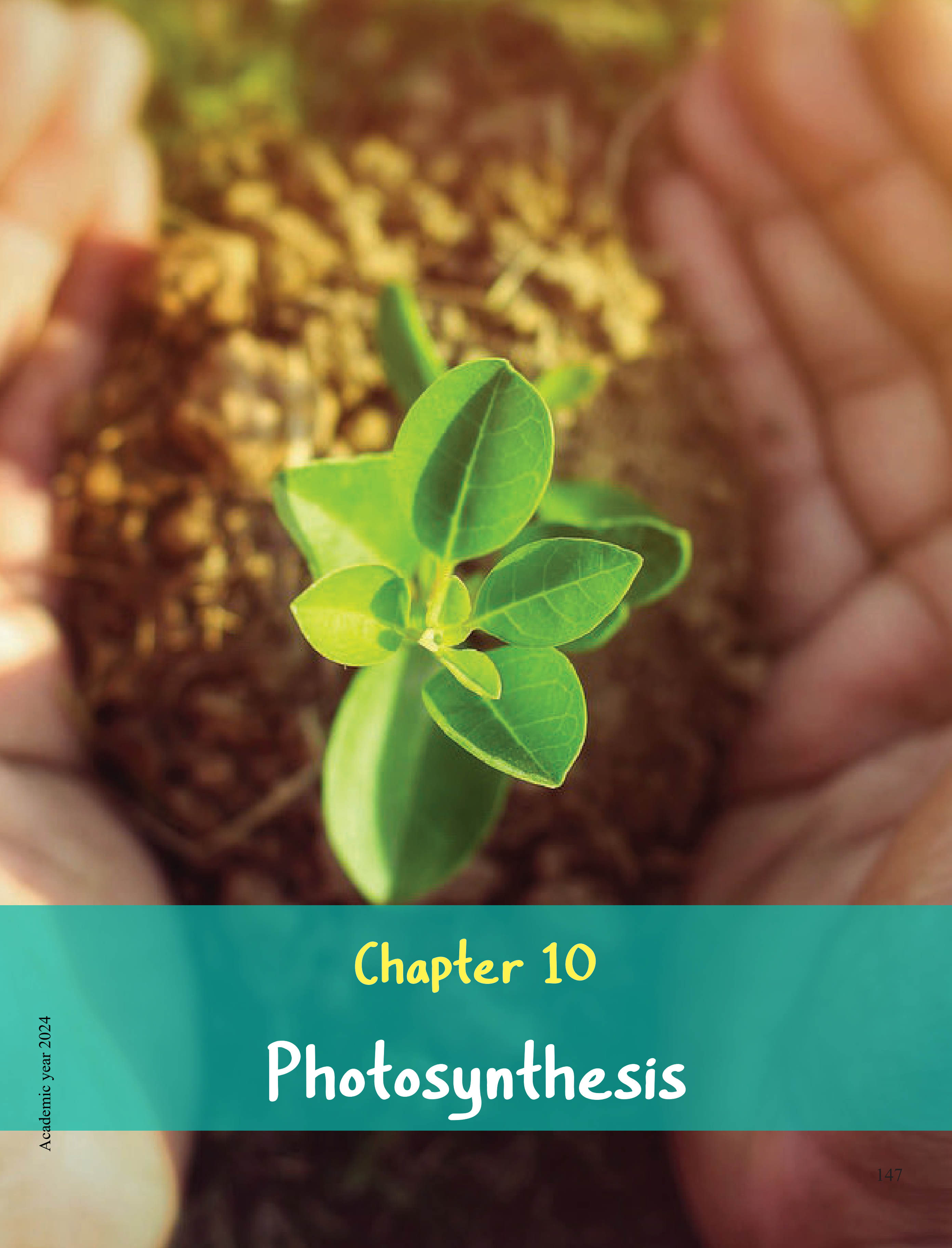
Carbohydrates and lipids: Carbohydrates are sometimes converted to glucose used as immediate energy, or stored as glycogen in the liver or muscles. Excess glucose is stored as long-term energy in a lipid called triglycerides.

Carbohydrates and Proteins: Carbohydrates can be directly attached to proteins in a process called glycosylation to convert into protein structures.

Proteins and Nucleic Acids: Proteins make up the structural components of our bodies, and they regulate essential reactions. The messages stored in DNA are expressed by making proteins. A type of protein called histone helps bind nucleic acids.

Proteins and lipids: A lipid called a phospholipid is essential for building the membrane of most cell membranes and often forms a lipid bilayer. By attaching proteins to this lipid bilayer, it creates channels, receptors or transporters that open the way for the movement of various types of organic molecules through the membrane. .

You must realize that organic molecules are intimately related to each other in order to keep the living world functioning. If there is a disturbance in this relationship, various types of complications are created in the activities of the living world



Chapter 10

Photosynthesis

Chapter 10 Photosynthesis

The following topics are discussed in this chapter:

- ☑ Conversion of solar energy into chemical energy
- ☑ Steps of photosynthesis in plants
- ☑ Carbon bonding

10.1 Photosynthesis

You know that seedlings are produced from seeds. These seedlings gradually grow larger and physically develop into full-grown plants. For many years, scientists have wondered what exactly contributes to this physical growth of plants over time. Is it water, nutrients obtained from the soil, light, or something else? Now we know that plants make their own food using sunlight, water and carbon dioxide from the air. This process is called photosynthesis, and not only plants depend on the food produced in this process, but all living beings on Earth depend on it directly or indirectly. The most important thing is that in this process, plants release oxygen gas as a surplus by-product, and we all survive by taking that oxygen.

On the eve of the creation of the Earth, our atmosphere was composed of nitrogen, carbon dioxide, and methane. But there was no oxygen then. As you have known from a previous chapter, about 2.5 billion years ago, a prokaryotic unicellular organism called cyanobacteria began to produce oxygen and carbohydrates, or sugars, through photosynthesis using sunlight and carbon dioxide. This ability later developed in algae. Algae, plankton, and fully developed plants now work together to ensure the supply of oxygen in our atmosphere, which has slowly transformed our atmosphere into its current state.

In this chapter, we will try to understand this very important process in nature called photosynthesis.

10.2 Conversion of Solar Energy into Chemical Energy

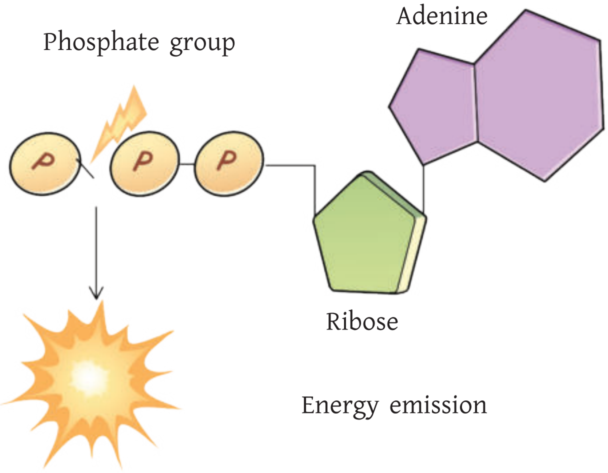


Figure 10.1: Energy is generated by breaking the phosphate bonds of ATP.

You already know that the leaves of plants appear green because of chlorophyll. The meaning of something being green is that it can absorb other colours of light but cannot absorb the green colour. So you must understand that during photosynthesis, the chlorophyll of the plant leaves absorbs the other colours it needs from the light and returns the green colour. This absorbed light energy, processed by chlorophyll, is used to complete the subsequent steps of photosynthesis. This chemical energy is stored in two molecules called ATP (Adenosine Triphosphate) and NADPH (Nicotinamide Adenine Dinucleotide Phosphate).

In a living organism, ATP stores energy for all reactions and supplies it as required. For this reason, ATP is also known as the biological coin of the cell (Figure 10.1). When you use your muscles, that energy is also supplied by this energy-storing biomolecule called ATP. The three phosphate groups in ATP are linked by strong chemical bonds, which store energy. When this chemical bond breaks and releases a phosphate group, energy is released for chemical reactions. (Image/Figure) When there are two phosphates instead of three, it is called ADP (ADP: Adenosine Diphosphate). Therefore, we can say that an important step in photosynthesis is to convert ADP to ATP, thereby converting solar energy into chemical energy.

In the case of NADPH, hydrogen (H) is added to NADP to convert solar energy into chemical energy in the chloroplast, and here too, the hydrogen (H) of NADPH can be released to obtain the necessary energy to complete the photosynthesis process.

10.3 The Site of Photosynthesis Process

The mesophyll tissue of the leaf is the primary site for the photosynthesis process.

Terrestrial green plants absorb water from the soil through the roots and reach the chloroplast of the mesophyll tissue of the leaf, and through the stomata, they take in carbon dioxide from the air, which reaches the chloroplast of the mesophyll tissue. The process of photosynthesis takes place from the beginning to the end in cytoplasmic organelles called chloroplasts.

Structure of Chloroplasts:

The structure of the chloroplast is illustrated in Figure 10.3. It is roughly 1–2 µm thick and 5–7 µm in diameter. The chloroplast is oval in shape and contains two membranes: an outer membrane and an inner membrane. Between the outer and inner membranes, there is a space of approximately 10-20 nm width called the intermembrane space. The space within the inner membrane is known as the stroma. In the granum (plural: grana) region of chloroplasts, the light of photosynthesis is absorbed and chemical energy is

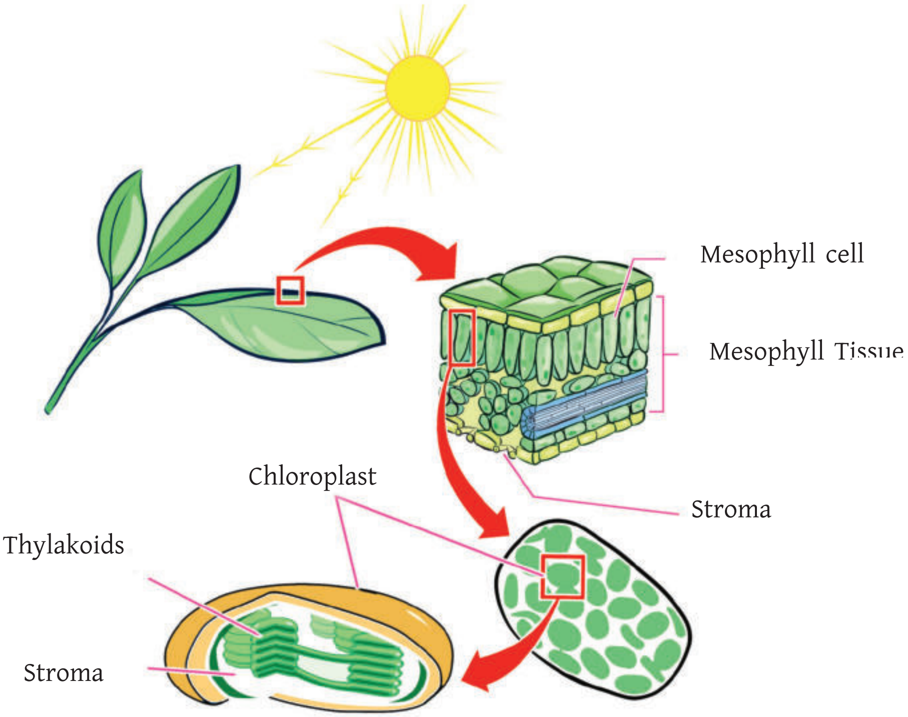


Figure 10.2: Structure of Chloroplast

produced, and in the stroma region, the reaction of forming carbohydrates from carbon dioxide is carried out using that chemical energy. Some of the organelles inside the chloroplast required for photosynthesis are:

Chlorophyll: It is a green photosynthetic pigment, and being a pigment, Chlorophyll absorbs light at a specific wavelength.

Thylakoids: They are composed of flat sac-like structures in the chloroplast. They hang within the stroma, where light energy is converted into chemical energy. Chlorophyll is present on the surface of thylakoids. It is to be noted that cyanobacteria do not have chloroplasts but have thylakoids, and on their surface, there are chlorophyll and other photosensitive pigments.

Grana (plural granum): Granum is formed by the aggregation of many (10 to 20) thylakoids, which are the site of the conversion of light energy into chemical energy.

10.4 The Process of Photosynthesis:

Photosynthesis is a physiological process in which chlorophyll in the cells of living plants captures light energy and stores it as chemical energy in organic molecules called ATP and NADPH. The chemical energy is then used to carry out the photosynthesis reaction. The reaction is as follows:

$$6CO_2 + 12H_2O \xrightarrow[\text{chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

You can see from the above chemical reaction that in the photosynthesis process, 1 molecule of hexose sugar (glucose) is produced from 6 molecules of CO_2 and 12 molecules of H_2O. Here, H_2O is oxidized to release O_2, while carbon dioxide is reduced by combining with hydrogen. Therefore, photosynthesis is called a complex oxidation-reduction process. Although there are many steps in the process of photosynthesis, it can be divided into two main phases: light dependent and light independent (Figure 10.3).

10.4.1 Light Dependent Phase

The phase of the photosynthesis process in which light energy is converted into chemical energy and stored in ATP and NADPH is called the light-dependent phase. Light is essential for this part. The chemical reaction is shown below:

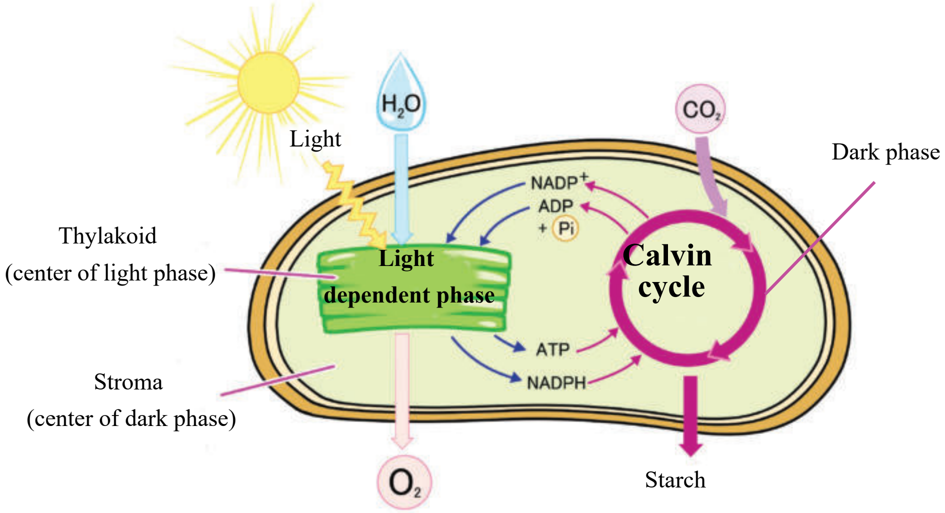


Figure 10.3: Light-dependent and dark phases of photosynthesis inside a chloroplast

$$2ADP + 2Pi + 2NADP + 4H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} 2ATP + 2NADPH + H^+ + 2H_2O + O_2$$

The above reaction shows inorganic phosphate as Pi.

Reactions in the photodependent phase of photosynthesis take place in the grana of chloroplasts in the presence of light.

The main events at this level include:

Activation of Chlorophyll: Chlorophyll plays an important role in this reaction. Chlorophyll molecules become active and energetic by absorbing photons of sunlight.

Photolysis: Active chlorophyll molecules split water to produce oxygen, hydrogen, and electrons. The generated oxygen is released into the environment through leaf stomata.

Photophosphorylation: In this process, the compound ADP (Adenosine Diphosphate) present in the leaf cell combines with inorganic phosphate (Pi) in the presence of sunlight to form the high-energy compound ATP (Adenosine Triphosphate).

Formation of reduced NADPH: The compound NADP present in the leaf cells combines with hydrogen ions, and forms reduced NADPH, which serves as a source of energy.

10.4.2 Light-independent Phase

In the light-dependent phase of photosynthesis, ATP and NADPH are produced using light energy. These are used as an energy source to produce carbohydrates or sugars by taking carbon dioxide from the air in the light-independent phase. After receiving energy from ATP and NADPH, they are converted to ADP and NADP respectively and again store energy in the light-dependent phase. The reactions take place cyclically in the stroma of the chloroplast with the help of enzymes and do not require light. The cycle is named the Calvin cycle after its discoverer, Dr. Melvin Calvin.

Photosynthesis converts carbon from its gaseous state into carbohydrates that other organisms on Earth can use. This is called carbon fixation. You may remember that life on Earth is carbon-based and carbon fixation in the Calvin cycle is one of the essential events for sustaining life. Photosynthesis does not always operate at maximum speed; the intensity of light, the amount of carbon dioxide, temperature, and the amount of water can also affect the rate of photosynthesis.

10.5 Importance of Photosynthesis

The main significance or importance of photosynthesis can be summarized into three points:

1. **Capturing the solar energy and converting it into stable energy in food:** The sun is the source of all energy on Earth. During photosynthesis, green plants absorb solar energy and convert it into chemical energy, storing within ATP molecules. Later, this energy is transformed into potential energy within the food produced. This energy is used by plants for various metabolic processes. Heterotrophic organisms acquire the necessary energy by consuming plant-based food. The energy contained in coal, petrol, etc., is solar energy trapped in plants

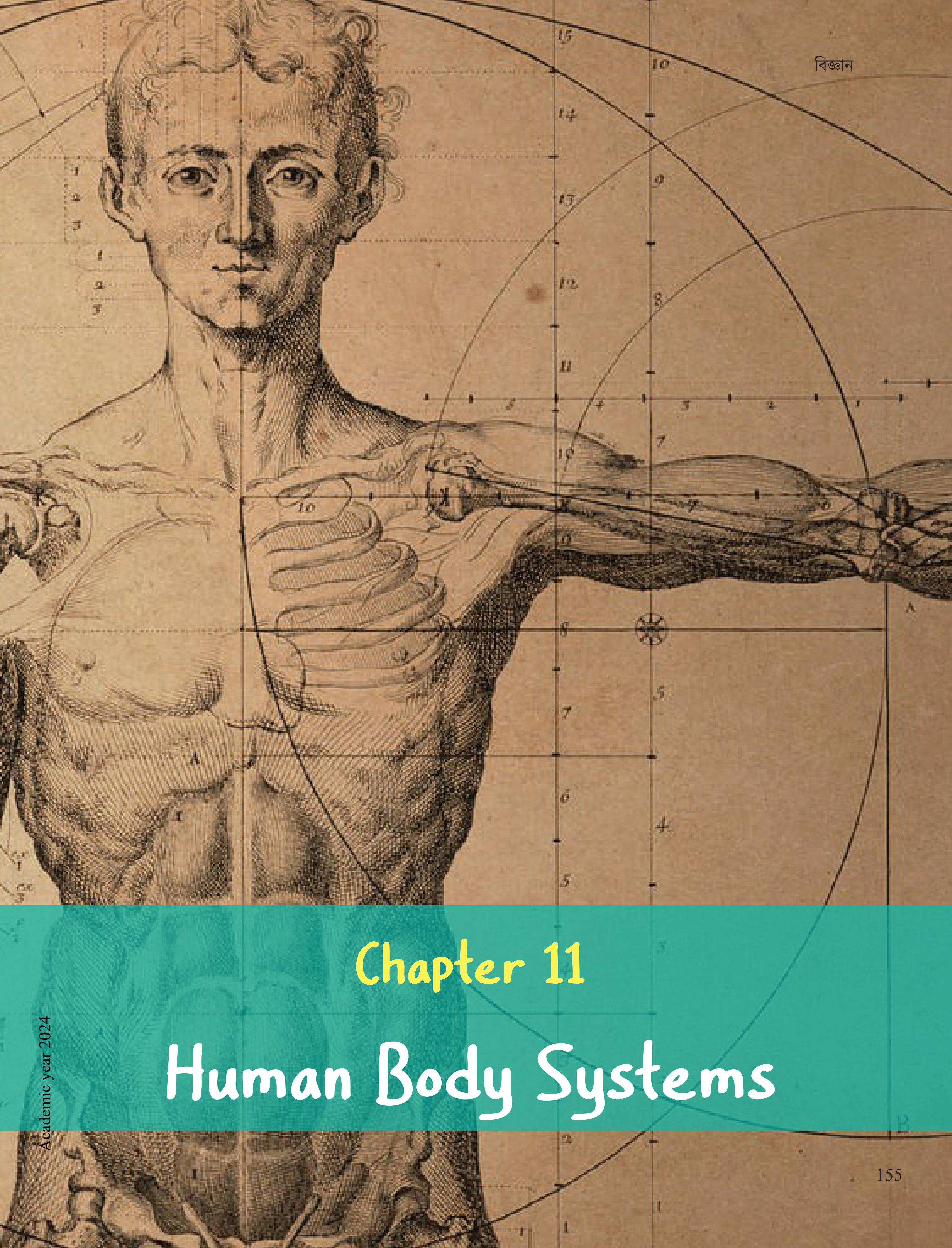
from many years ago.

2. Conversion of glucose into carbohydrates and transportation to storage organs:

The simple sugar glucose is produced during the process of photosynthesis. It is then converted into carbohydrates and stored in various storage organs of the plant, such as fruits, roots, and seeds. Proteins, fats etc. are synthesized from glucose. Heterotrophs consume these plant foods directly or indirectly. Therefore, the food produced by photosynthesis is the main source of food.

3. Maintaining the Balance of Oxygen and Carbon Dioxide in the Environment:

The natural balance of gases in the atmosphere includes approximately 0.04% CO_2 and 21% O_2. During photosynthesis, green plants help maintain the balance of O_2 and CO_2 in the environment by absorbing carbon dioxide and releasing oxygen.



Chapter 11

Human Body Systems

Chapter 11 Human Body Systems

The following topics are discussed in this chapter:

☑ Nervous system
☑ Endocrine system
☑ Important hormones of human body
☑ Cardiovascular system
☑ Introduction to the immune system of the human body
☑ General process of the immune system

11.1 Nervous system

The system of the human body that manages the functions of various organs of the body, coordinates among them and responds to external stimuli is called the nervous system. At the center of all the activities of the human body are the nerve fibers that maintain communication between the brain and senses. The nervous system is divided into two main parts: central nervous system and peripheral nervous system.

11.1.1 Central nervous system

The central nervous system consists of the brain and the spinal cord. The brain remains protected within the cortex while the spinal cord within the backbone.

Brain:

You all know about the brain— it is the swollen part of the central nervous system found in the cortex above the spinal cord. The human brain is the most important organ in the body. The brain is the regulator of the nervous system; it controls every part of the body, even human feelings and thoughts. An adult human brain weighs 1.4 kg. The brain has three sections cerebrum, stem and cerebellum (Fig. 11.1).

Cerebrum: The uppermost part of the brain is called the cerebrum. The right and left halves of the cerebrum are completely divided. This separation occurs because of the segregation groove between the two parts. These two parts are called cerebral hemispheres. Even though there's a gap between the right and left hemispheres of the cerebrum, they're connected by a bunch of neurons called the corpus callosum. The left cerebral hemisphere controls the right side of the body and the right cerebral hemisphere controls the left side of the body. There are many types of grooves and folds on the cerebrum. The cerebrum controls our thinking, consciousness, cognition, memory, will, speech and functions of the voluntary muscle. In addition, it helps to decide what kind of response to give to a stimulus.

Stem: The part of the brain that is connected to the spinal cord is called the stem. Stem controls the involuntary physiologic processes of the human body—like heart rate, breathing, hunger, thirst, temperature, etc.

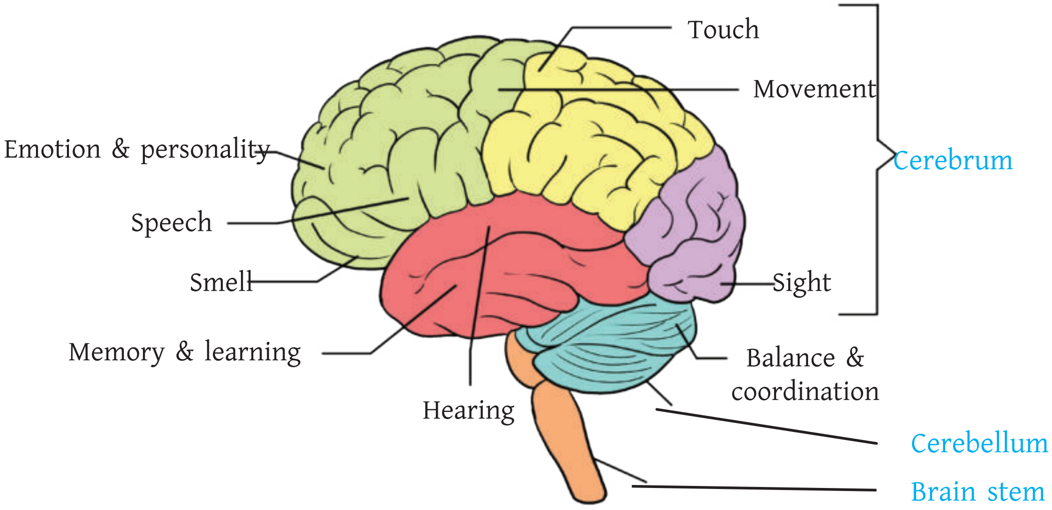


Figure: 11.1 : Cross section of the brain

Cerebellum: The cerebellum is located in the back of the head, between the stem and the cerebrum. It controls muscle pull, coordination, balance, and the functions of the muscles involved in running and jumping.

Twelve pairs of cranial nerves emerge from the brain and spread to the head, neck, face, oral cavity, tongue, eyes, nose, ears, etc. Its nerves control swallowing of food and some functions of the heart, lungs, and pharynx. In addition, these nerves are also involved in important functions such as hearing and balance.

Spinal Cord:

The spinal cord emerges from a hole in the back of the skull and travels through the vertebral column in a protected condition to the lumbar region Thirty-one pairs of spinal nerves branch off from the spinal cord through the spaces between the vertebral bones. These are the nerves of the neck, throat, chest, back, hands and feet.

11.1.2 Peripheral nervous system

The 12 pairs of nerves that emerge from the brain and the 31 pairs of nerves that emerge from the spinal cord divide into very finer branches and spread throughout the body. These nerves are collectively called the peripheral nervous system (Figure 11.2). Cranial nerves that originate from the brain control the functions of organs such as the eyes, nose, ears, tongue, teeth, face, heart, and stomach. The nerves that emerge from the spinal cord control the organs and carry all sensations from the rest of the body to the brain.

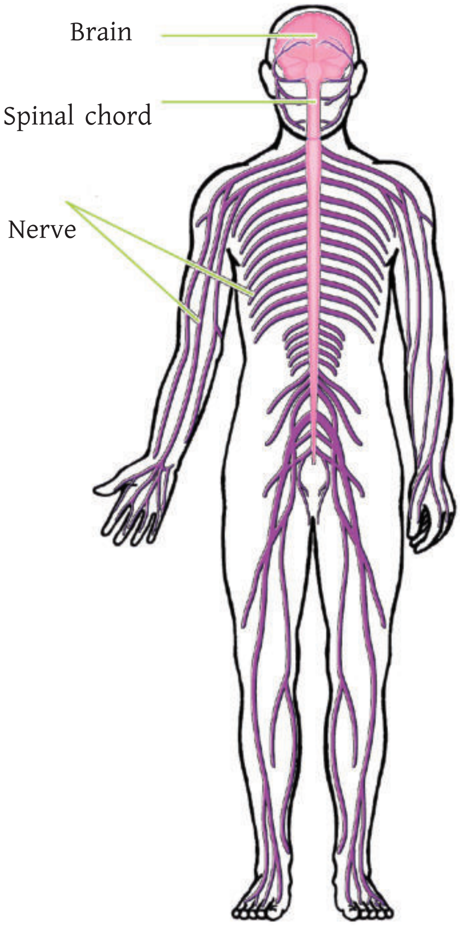


Figure 11.2: Human Nervous System

Peripheral nervous system can be further divided into somatic nervous system and autonomic nervous system.

Somatic Nervous System

The somatic nervous system is the part of the peripheral nervous system that uses muscles attached to the bones of our body to move. When we consciously move any part of our body like arms, legs or other limbs, the somatic nervous system moves it. When we want to grab something with our hands or push something with our feet, the somatic nervous system sends the necessary signals to the muscles of the hands or feet.

Autonomic Nervous System:

Organs over which we have no control are operated and regulated by the autonomic nervous system. The internal organs of the body, such as the heart, intestines, stomach, pancreas, etc., are operated by the autonomic nervous system. Since the brain and spinal cord do not directly influence the functionality of these systems, they operate somewhat independently and perform their tasks autonomously. The autonomic nervous system is further divided into the sympathetic nervous system and the parasympathetic nervous system.

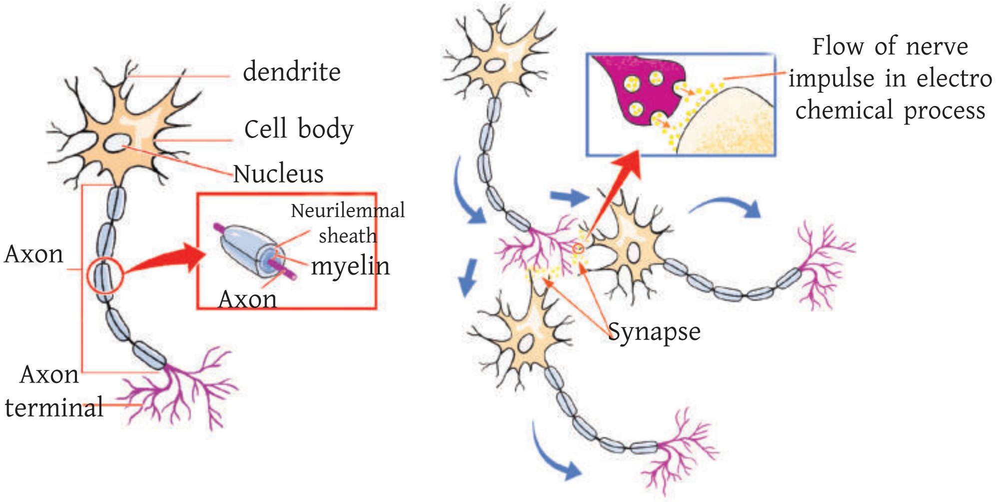


Figure 11.3: (Left) a neuron (Right) Flow of nerve impulse.

When suddenly exposed to something alarming or exciting, the sympathetic nervous system becomes active, increasing our heart rate and hardening muscles and prepares the body to do something instantly. After the body becomes suddenly aroused, the parasympathetic nervous system works to calm the body down.

11.1.3 Neuron

Nerve tissues are the tissues that receive all types of sensations and stimuli of the body and by transporting them create an appropriate response according to the stimulus. The unit of structure and function of the nervous system is called a neuron (Figure 11.3). The nerve tissue is composed of a large number of nerve cells or neurons. Each neuron consists of two parts, the cell body and the elongated segment.

Cell Body:

The round, star-shaped, or oval part of a neuron, consisting of a plasma membrane, cytoplasm, and nucleus, is known as the cell body. It contains numerous Nissl's granules, as well as mitochondria, Golgi apparatus, lysosomes, fat, glycogen, and pigment particles in the cytoplasm.

Elongated segment:

Branches extending from the cell body are called elongated segments. The elongated segments are of two types:

(i) Dendron: The small, elongated parts with branches around the cell body are called dendron. The branches emerging from the dendron are called dendrites. The number of dendrons in a neuron can range from zero to hundreds. The dendrites of one neuron receive nerve impulses from another neuron.

(ii) Axon: The long fiber that originates from the cell body is called the axon. The thin covering around it is called neurilemma. Between the neurilemma and the axon is a layer of connective tissue called myelin. The end of the axon is divided into axon terminals, and through these terminals a neuron sends nerve impulses to the dendrites of another neuron.

The axon terminal of one neuron is not directly connected to the dendrite of another neuron, but there is a small gap between them. This little gap is called a synapse, which is the junction between two neurons. The nerve impulse flows through the synapse from the axon terminal to the dendrite in the electrochemical process. The nerve impulse flows through one neuron, passes through the synapse, and goes to the next neuron. That is, the nerve impulse flows in one direction through the synapse. The human brain has about 100 billion neurons, and each neuron makes synapse connection with seven to ten thousand other neurons.

When someone thinks, one neuron connects to another neuron through a synapse. Therefore, if someone reads a book or solves a problem, s/he stimulates specific synapse connections and makes the brain more efficient.

Transmission of Impulse:

Stimuli or impulses travel through countless interconnected nerve fibers, finally reaching the brain. Its speed is about 100 meters per second, but it may vary depending on the nerve.

The signal that flows through the nerve from the environment to the brain is called nerve impulse or nerve stimulus. Due to the functioning of the neuron, this stimulus is sent to the necessary organs. When it reaches the muscle, the muscle contracts and responds, causing various organs of the body to move as needed. When this impulse reaches the gland, it secretes juice. When the sensory nerve is stimulated, the impulse moves towards the brain, causing the perception of sight, hearing, touch, or pain.

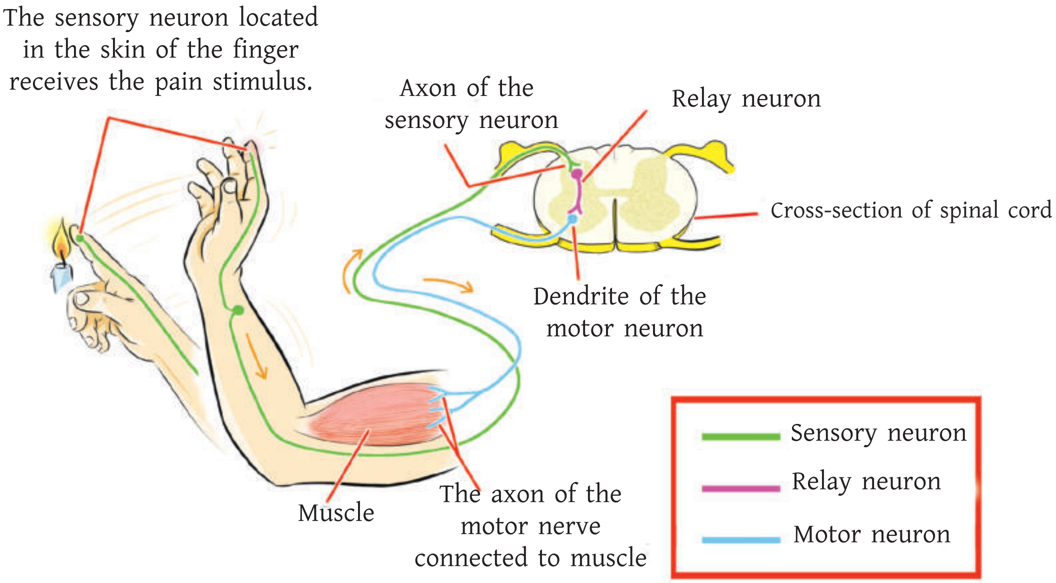


Figure 11.4: Reflex action of the human body

If you shine a torch in your friend's eye, you will see that the pupil of the eye will shrink immediately after the light is shone. When the light stimulus reaches the brain from the light-sensitive cells of the eye, the circular or round muscle of the iris contracts to shrink the pupil at the instruction of the brain.

11.1.4 Reflex action

Reflex action is defined as the automatic response to a sudden stimulus. When a needle suddenly pricks our finger or something hot falls on our hand, we quickly pull away our hand from the spot of stimulation. This is the result of a reflex action (Figure 11.4). We cannot control reflex actions, even if we want to, because reflex actions are not controlled by the brain, but by the spinal cord. Reflex actions are those responses to stimuli that are controlled by the spinal cord, not by the brain.

The reflex action of the hand pulling away immediately after the finger carelessly touches the flame of a burning candle can be explained as follows:

- As soon as the heat of the fire touches the finger, the sensory neuron located in the skin of the finger receives the pain stimulus. Here, the skin acts as a receptor organ.
- The stimulus from the skin of the finger reaches the spinal cord through the axon of the sensory neuron.
- The stimulus from the axon of the sensory neuron located in the spinal cord enters the dendrite of the motor neuron through the intermediate or relay neuron by the method of electrochemical process.
- The stimulus enters the muscle through the axon of the motor nerve.
- When the stimulus reaches the muscle, the muscle contracts. As a result, the hand quickly moves away from the source of stimulation or the flame.

11.1.5 Physical problems related to neurological disorders

(a) Paralysis:

Paralysis is the loss of the ability to move a voluntary muscle of any part of the body. Generally, due to damage to any part of the brain, the muscles receiving sensation in that part lose functioning. Paralysis is often caused by stroke. Paralysis can also be caused by injuries or accidents to the spine or spinal cord in the neck or back.

(b) Epilepsy:

Epilepsy is a disease of the brain in which the body of the affected person has convulsions or shaking. In many cases, due to this disease, the affected person suddenly loses activity temporarily, the body shakes and falls to the ground, and in many cases, the patient becomes unconscious. The root cause of epilepsy is still not fully identified. Epilepsy symptoms can also occur due to head injuries, meningitis, encephalitis, congenital brain malformations, tumors etc.

(c) Parkinson's disease:

Parkinson's disease is a condition of the brain that causes shaking in the hands and feet and makes it difficult for the patient to move and walk. This disease usually occurs after the age of 50. Nerve cells produce various types of chemicals, one of which is dopamine. Dopamine helps to move the muscles of the body. In patients with Parkinson's disease, the cells that produce dopamine in the brain are slowly destroyed. As these nerve cells cannot send signals to the muscle cells without dopamine, the muscles lose their functioning.

11.2 Endocrine System:

The endocrine system is a very important system in the human body. This system is composed of several ductless glands in the human body (Figure 11.5). The secretions of these ductless glands are called hormones. Various types of hormones circulate through the blood and regulate various physiological functions of the body. Since there is no separate duct for the transportation of hormones, it flows through the bloodstream and reaches the target cells, affecting the biochemical activities of the cells and conducting biological functions smoothly. Hormones are secreted regularly from the gland according to the needs of the healthy body. But if less or more than required amounts of hormones are secreted, various unwanted reactions are created in the body.

11.2.1 Some important glands of human body

(a) Pituitary gland: This is the smallest gland in the human body and is located at the lower part of the brain. Though the smallest, the pituitary gland is the main hormone-producing gland in the human body. The pituitary gland secretes the most hormones and has a greater effect on other glands. It controls the growth of the human body in addition to influencing other glands.

(b) Thyroid gland: The thyroid gland is located in the neck, on the upper part of the trachea. This gland mainly secretes thyroxine hormone. The hormone thyroxine secreted from the thyroid gland generally controls normal growth and metabolic functions in the human body. Another hormone of the thyroid is involved in calcium metabolism in the human body.

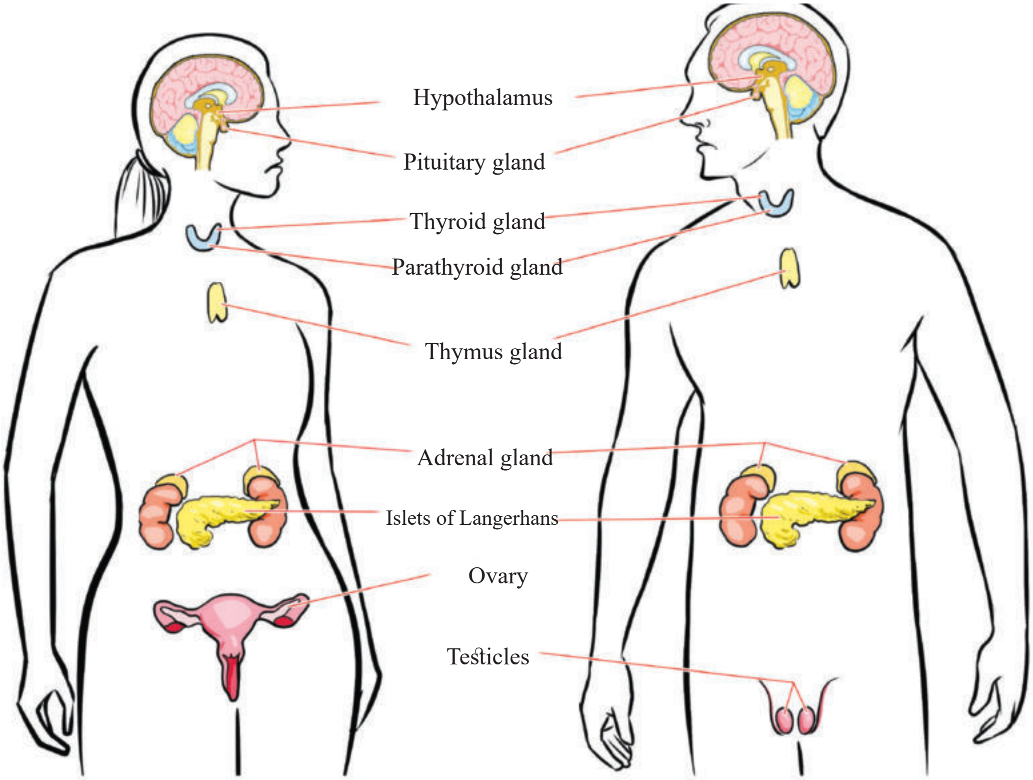


Figure 11.5: Major ductless glands of the human body

(c) Parathyroid gland: A human usually has four parathyroid glands, all of which are located behind the thyroid gland. The hormone secreted from this gland primarily controls the metabolism of calcium and phosphorus.

(d) Thymus gland: The thymus gland is located in the neck region. The thymus gland helps to develop the body's immune system. This gland develops in childhood and then shrinks with age. In adults, this hormone is usually not present. This gland produces several hormones that play a role in the production of white blood cells in the thymus.

(e) Adrenal gland: The adrenal gland is located on top of the kidneys. The adrenal gland controls the body's essential metabolic activities. This gland mainly helps to recover from severe mental and physical stress. One of the hormones secreted from this gland is adrenaline. Adrenaline hormone controls the contraction of involuntary muscles of the heart and blood vessels and plays a special role in expressing fear, joy, and sorrow.

(f) Islets of Langerhans: The islets of Langerhans are located in the pancreas, and these cell clusters regulate the body's carbohydrate metabolism. This gland secretes insulin, which regulates blood glucose levels. Since insulin controls the body's carbohydrate digestion, if the pancreas does not produce enough insulin, the amount of sugar in the blood permanently increases.

(g) Pineal body: This is a round-shaped gland attached to the brain. The hormone secreted from this gland is melatonin, which regulates the body's day-night cycle.

(h) Gonads or reproductive organs: This is located in the ovaries of girls and the testicles of boys. Hormones secreted from the gonads play a role in developing the signs of maturity in the body. In addition to the growth of the animal's reproductive organs, it controls the reproductive cycle and sexual behaviour. Testosterone and oestrogen are produced from the gonads in the mature male and female bodies, respectively.

11.2.2 Hormonal abnormalities

(a) Thyroid problems: Thyroid hormones are produced when iodine-rich foods are consumed. As seawater contains iodine, seafood is one of the main sources of iodine in human food. Due to the lack of iodine, goiter disease occurs. So, in the past, the number of patients with this disease was more common in areas far from the sea. The prevalence of this disease has been eliminated today due to the use of iodized salt in food. In addition to goiter, if there is a deficiency of thyroid hormones, the mental development of children is also hindered and there is a difference in appearance from normal children. This problem can be avoided by eating bananas, fruits, and taro, in addition to seafood.

(b) Diabetes: If the pancreas does not produce enough insulin, the body cannot regulate the digestion of carbohydrate in the blood. So, the amount of carbohydrate in the body permanently increases, which is called diabetes. Diabetes is mainly of two types- type 1 and type 2. In type 1, the body of the affected person does not produce any insulin at all. Therefore, the affected person must take insulin regularly through injection. On the other hand, in type 2, the body of the affected person produces insulin partially. In this case, the medicine helps the pancreatic cells to produce the right amount of insulin for the body. A person with diabetes can often control it with a disciplined lifestyle, moderate diet, and regular exercise.

11.2.3 Important Hormones in the Human Body

Human body has many types of hormones. Scientists have identified over half a hundred of them as important hormones. Here are the names of some important hormones, their functions, and glands of secretion of them are given below:

1. Insulin: Controls blood sugar by sending the blood glucose to body cells; it is produced in the islets of Langerhans of the pancreas.

2. Thyroid hormone or thyroxine: Controls metabolism and energy production of the body; produced in the thyroid gland.

3. Cortisol: Controls mental stress, body growth, and immune activities; produced in the adrenal gland.

4. Adrenaline: Prepares for difficult mental and physical stress; produced by the adrenal gland.

5. Testosterone: Ensures growth of male reproductive organs as well as controls the reproductive cycle and sexual behaviour. Produced in the male testicles.

6. Estrogen: Ensures growth of female reproductive organs as well as controls the reproductive cycle and sexual behaviour. Produced in the female ovaries.

7. Progesterone: Prepares the uterus for childbirth and helps during pregnancy; produced in the female ovaries, especially in the corpus luteum.

8. Growth hormone: Helps in physical growth, cell division; produced by the pituitary gland.

9. Melatonin: Controls the sleep-wake cycle and the sense of day and night; produced by the pineal gland.

10. Oxytocin: Promotes social bonding, helps in childbirth, and helps in the release of breast milk; produced by the hypothalamus and released by the pituitary gland.

11.3 Blood Circulation:

Blood is the source of vitality. Through the blood vessels, blood flows throughout the body and provides oxygen and nutrients to the cells, keeping all the cells of the body alive and active. At the same time, the waste products of the blood are transported from one place to another in the body. The system through which blood circulates continuously in various organs and parts of the body is called the circulatory system.

In the human body, blood flow is limited to the heart and blood vessels, never coming out of it. This type of circulatory system is called a close circulatory system. It takes only one minute or less for blood to complete a full circulation throughout the body. The major advantage of the closed circulatory system is that in this system,

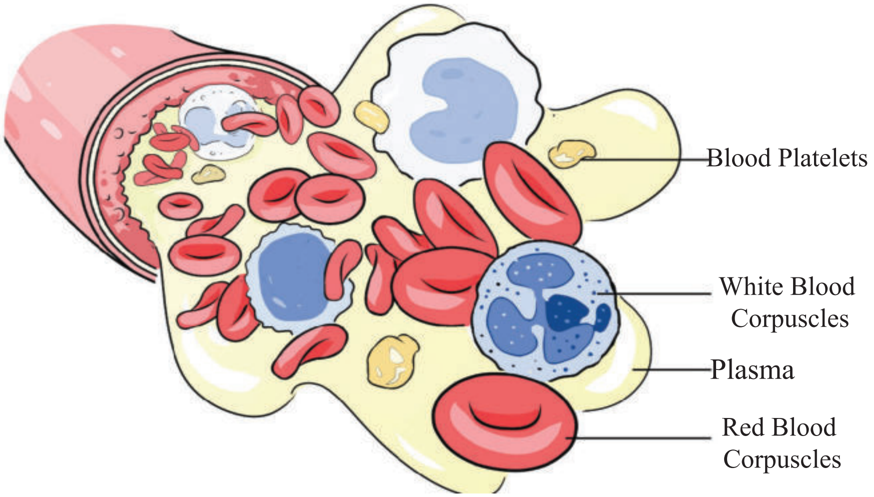


Figure 11.6: Different types of blood cells

(a) Blood directly reaches the various organs of the body.

(b) The body can regulate the amount of blood flow to a particular organ by changing the diameter of the blood carrying vessels.

(c) Blood circulates through the various organs and quickly returns to the heart.

Although the circulatory system is unique compared to other systems, its structure is fairly simple.

11.3.1 Blood

Blood is an opaque, slightly alkaline, and salty liquid substance. Blood circulates through the heart, veins, venules, arteries, arterioles, and capillaries. The colour of blood is red due to the presence of a pigment called haemoglobin in red blood cells. Blood cells are produced in the red bone marrow of bones.

Components of blood

Blood is a type of liquid connective tissue. It is composed of plasma and several types of blood cells (Figure 11.6).

Figure 11.7: Red blood cell

(a) Plasma: Plasma is the colourless liquid portion of blood. It usually makes up about 90% of blood. The main component of plasma is water. In addition, the other components of the remaining part are proteins, glucose, small fat particles, minerals, vitamins, hormones, and antibodies. Waste products such as carbon dioxide, urea, and uric acid are also present in plasma. The food we eat is digested and absorbed in the intestine and circulates throughout the body getting mixed with plasma. In this way, body cells receive nutrients and maintain the body's nutrition and repair.

(b) Blood corpuscles:

There are three types of blood cells in the human body - Red Blood Corpuscles, White Blood Corpuscles and Blood Platelets. Although they are all cells, they were long ago given the name blood cells comparing them to the particles floating in blood plasma, a name that is still in use today.

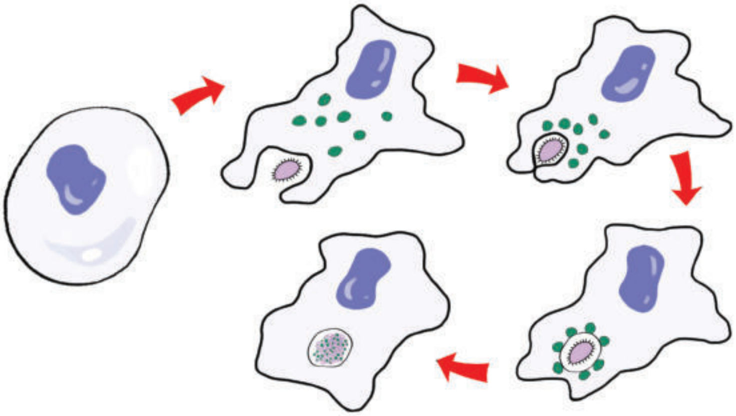


Fig. 11.8 : White blood cells destroy microbes by the process of phagocytosis.

Red Blood Corpuscles (RBC): Among the three types of blood cells in the human body, red blood cells have the largest number (Figure 11.7). Red blood cells are made in red bone marrow. Its average lifespan is 120 days. Human red blood cells do not have a nucleus and look more like biconcave spheres. The number of red blood cells in the blood of an adult is about 50 lakhs per cubic millimetre. It is about 500 times more than white blood cells. Women have fewer red blood cells than men. Comparatively, children have more red blood cells in their bodies. Every moment of our life, red blood cells are destroyed, and an equal amount is made. Red blood cells play an important role in oxygen transport in respiration, its haemoglobin transports oxygen. Haemoglobin is a type of pigment. The presence of haemoglobin in RBCs makes blood appear red. If there is not enough haemoglobin in the blood, anaemia occurs.

White Blood Cell (WBC) or leukocyte: White blood cells are large cells having no haemoglobin and nuclei. They are called white blood cells because they do not have haemoglobin. White blood cells contain DNA. The number of white blood cells is much less than that of RBC. White blood cells have no fixed shape, they change body shape like amoeba (Figure 11.8). They destroy microbes by the process of phagocytosis.

White blood cells can move on their own through the plasma and enter tissues penetrating

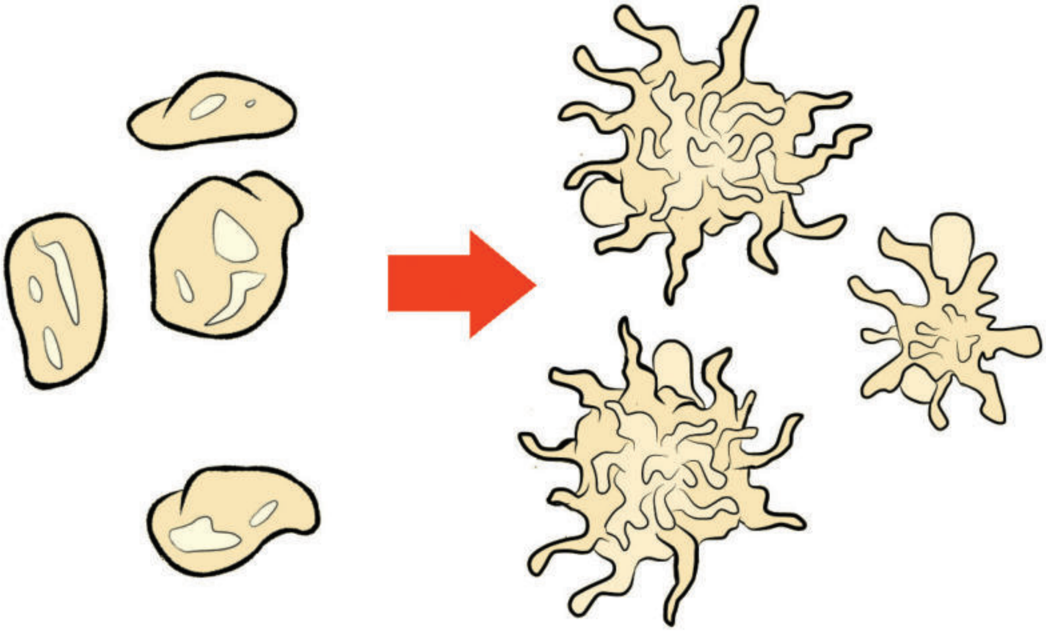


Fig. 11.9: Platelet and changes of its shape

the wal of the capillaries. The average lifespan of white blood cells is 1-15 days. When the body is infected by foreign microbes, the white blood cell count rapidly increases. Human body has 4-10 thousand white blood cells per cubic millimetre of blood. Its number increases in the sick human body.

Platelet: Platelets can be spherical, oval or rod shaped. Their cytoplasm is granular and cytoplasm contains cell organelles mitochondria, Golgi apparatus; But there is no nucleus. The average lifespan of platelets is 5-10 days. In the mature human body, the number of platelets per cubic millimetre of blood is about two and a half lakhs. The main function of platelets is to form blood-clotting. When a blood vessel or tissue is injured and severed, the platelets are activated and take an irregular form (Fig. 11.9) and stop bleeding by helping to form blood-clotting at the wound site. Bleeding does not stop easily if the blood does not contain adequate amounts of platelets.

Functions of blood:

Blood is an important component of the body. It performs various functions in the body, such as:

(1) Oxygen transport: Red blood cells transport oxygen to the cells.

(2) Removal of carbon dioxide: The carbon dioxide produced in the cells as a result of chemical reactions is collected by plasma and red blood cells and brought to the lungs and exhaled out of the body.

(3) Transport of nutrients: Plasma supplies glucose, amino acids, lipids etc. to cells.

(4) Maintenance of Heat Balance: Continuous combustion is taking place in the body, thereby generating heat of different degrees in different organs and it spreads throughout the body through the blood. In this way, heat balance is maintained throughout the body.

(5) Excretion of waste products: Blood carries harmful waste products and removes them as urea, uric acid and carbon dioxide through various organs.

(6) Hormone transport: Hormones are directly mixed with blood and circulated to various organs as needed and play important roles in various biological functions.

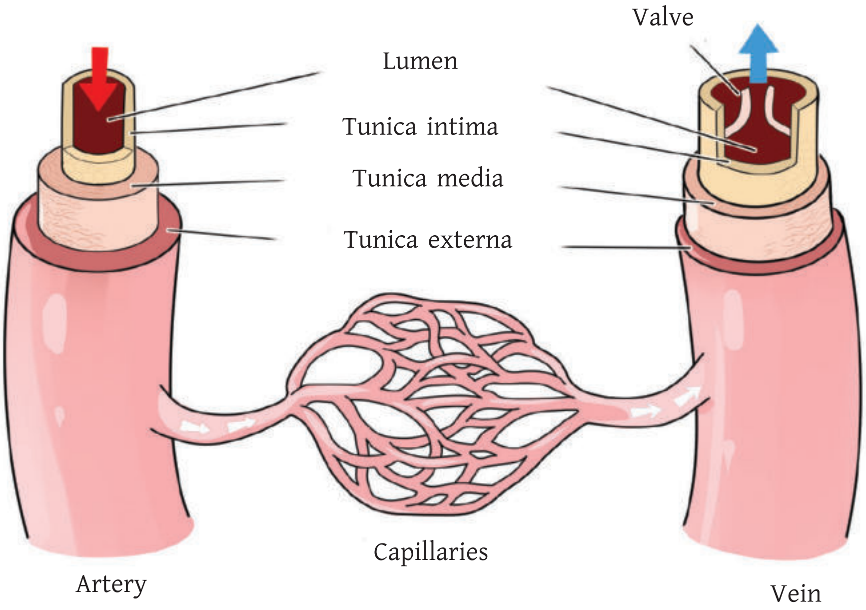


Figure 11.10: Different types of blood vessels

(7) Immunity: Several types of white blood cells protect the body from microbial attack by the process of phagocytosis. Blood increases the body's immune system by producing antibodies and antigens.

(8) Blood clotting: When a part of the body is cut, platelets help the blood to clot and stop the bleeding of the body.

11.3.2 Blood Vessel:

The vessels through which blood flows are called blood vessels (Fig. 11.10). Through these vessels blood flows from the heart to different parts of the body and returns to the heart from different parts of the body. These blood vessels are divided into three parts based on their structure, shape and function, namely: arteries, veins and capillaries.

(a) Artery: The blood vessels through which blood is carried from the heart to the whole body are called arteries. Blood in all arteries except the pulmonary artery is rich in oxygen. The pulmonary artery carries carbon dioxide-rich blood from the heart to the lungs.

Arterial walls are thick and elastic, their ducts are narrow, and they have no valves. During each contraction and expansion of the heart, the dilated arterioles contract as blood flows through the arteries throughout the body. This expansion and contraction of the arteries is called the pulse. Blood flow within the arteries, constriction, dilation and elasticity of the arterioles are the main causes of the pulse. You can feel this pulse by placing your hand on the artery in the wrist.

(b) Vein: The vessels through which blood returns to the heart from different parts of the body are called veins. All veins except the one from the lungs to the heart carry blood containing carbon dioxide to the heart. Only the pulmonary veins carry oxygen-rich blood from the lungs to the heart. Like arteries, veins are spread throughout the body. Veins originate from capillaries in various parts of the body and numerous capillaries join together to form the vena cava, vena cava, vena cava and finally the vena cava and return to the heart. Vein walls are also three layered like arteries. Their canals are slightly wider and have pits. Their walls are less thick, less elastic and less muscular.

(c) Capillaries: Muscle fibres have very fine blood vessels like hairs. It is called capillaries. They connect the smallest arteries on one side and the smallest veins on the other. As a result, arteries branch off and gradually turn into finer capillaries that surround each cell. Their walls are very thin. Through this thin wall, all substances dissolved in the blood can enter the cell by diffusion process.

11.3.3 Structure and function of the heart

Structure of the heart

The heart is a triangular hollow organ located between the two lungs on the left side of the thoracic cavity. It is made up of a special type of involuntary muscle called cardiac muscle.

The inner layer of the heart is hollow and divided into four chambers. The upper two chambers are smaller in size than the lower two. The two upper chambers are called right and left atrium and the lower two chambers are called right and left ventricle. The heart has

valves to open or close the openings between both the atria and the ventricles and between the ventricles and the arteries. Due to their shape, they can only open on one side and therefore pumped blood cannot return in the opposite direction.

Blood circulation system in the heart

When the two atria in the heart are expanded, blood from different parts of the body enters the heart. Blood containing carbon dioxide enters the right atrium through the superior and

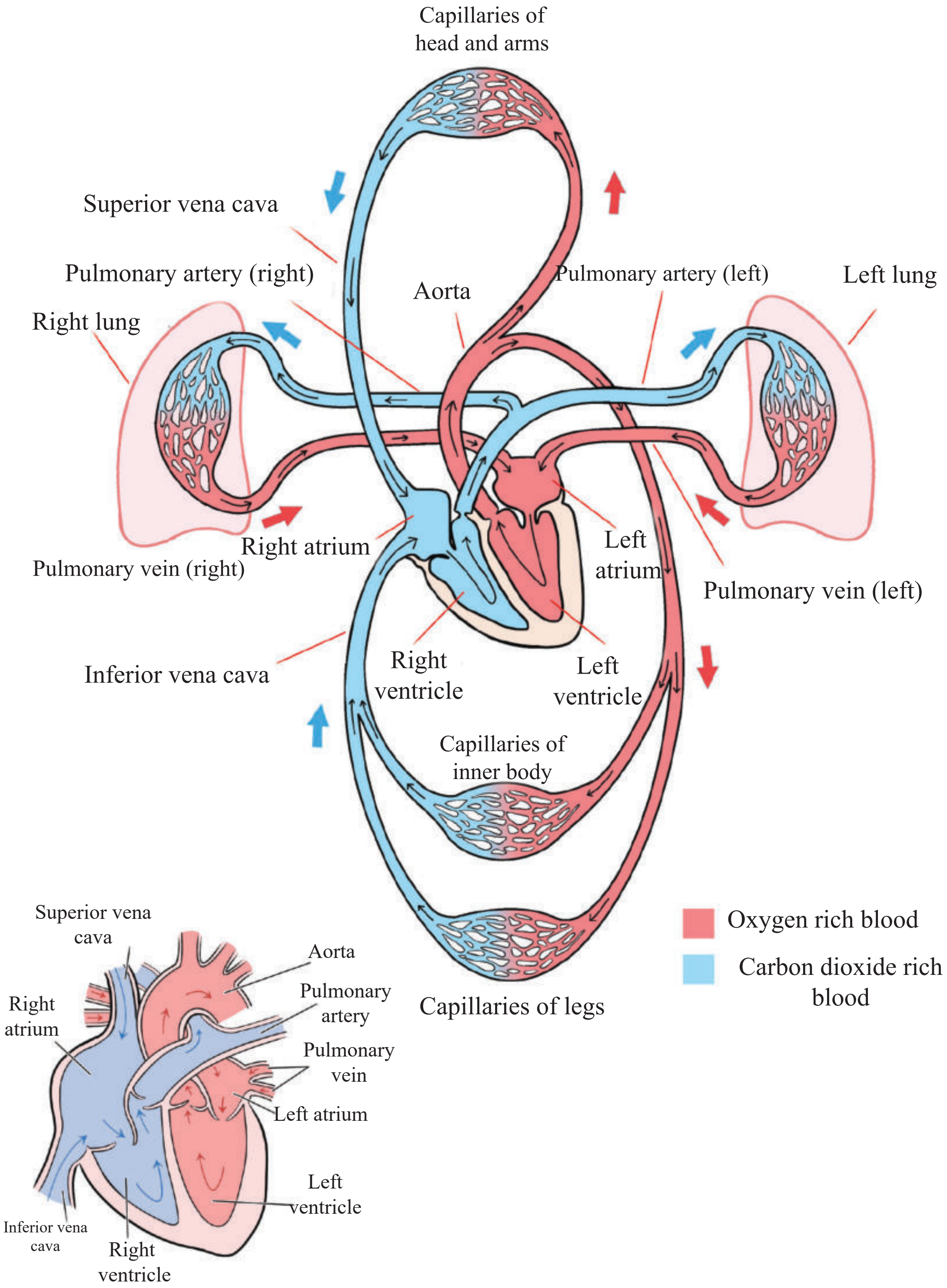


Figure 11.11: Human heart and blood circulation

inferior vena cava, and oxygen-rich blood enters the left atrium through the two pulmonary veins (Fig. 11.11).

When the upper atria contract, muscles of the lower ventricles get expanded. Then the right atrioventricular valve opens and carbon dioxide-rich blood from the right atrium enters the right ventricle. Right at that time, the valve in the loopholes between left atrium to left ventricle opens and then oxygen-rich blood from the left atrium enters the left ventricle. Immediately after this, the loopholes are closed by the valves, and blood from the ventricles can no longer enter the atria.

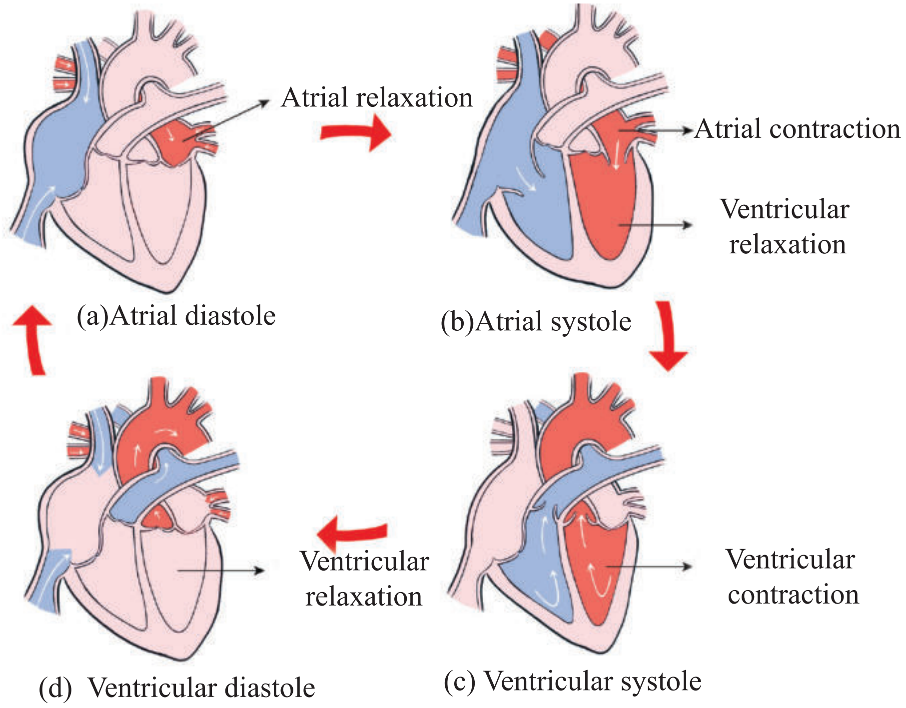


Figure 11.12: Stages of blood circulation in the heart

When the two ventricles contract, blood containing carbon dioxide from the right ventricle enters the lungs through the pulmonary artery to purify the blood. At the same time oxygen-rich blood from the left ventricle is pumped throughout the body through the aorta and the valves of both arteries close. As a result, the blood can no longer return to the vessel. Thus, the periodic contraction and expansion of the heart continues the process of blood circulation (Fig. 11.12).

Function of the heart: The heart is the main organ of the circulatory system. It helps the blood flow of the circulatory system to remain active. Since the chambers of the heart are completely separated, there is no mixing of oxygen-rich and dioxygen-poor blood.

11.3.4 Some Diseases of Blood Circulatory System

High Blood Pressure: One of the main causes of heart disease and stroke is high blood pressure. Blood pressure refers to the force created in the arteries during blood circulation. When the blood pressure is higher than normal, it is called high blood pressure. In the case of an adult, normal blood pressure is generally considered to be a systolic pressure below 120 millimeters of mercury (mmHg) and a diastolic pressure below 80 mmHg. When the blood pressure exceeds these values, it is termed high blood pressure.

Heart Attack: When blood flow to a part of the heart is blocked or restricted due to the buildup of blood clots or atherosclerosis, the cells or tissues in the heart muscle may be damaged. The problems that arise as a result of this condition are collectively known as a heart attack. The heart pumps oxygen and essential nutrients through the blood to various parts of the body. For the heart to perform its functions properly and obtain oxygen and nutrients, three main blood vessels in the heart muscle are essential. Sometimes, these vessels may become blocked due to the accumulation of fat, leading to a disruption in blood flow. This can result in a life-threatening condition known as a heart attack. Unhealthy eating habits, such as consuming a diet high in saturated fats, leading a sedentary lifestyle, and lack of physical activity, can contribute to the development of this condition.

High Cholesterol in the Blood: Similar to other parts of the body, the heart requires oxygen and a constant supply of nutrients for proper functioning. When fat accumulates in the coronary arteries of the heart, it can impede the normal flow of blood, leading to insufficient oxygen and nutrient delivery to the heart muscle. Reduced blood flow can cause chest pain, known as angina. Additionally, excessive fat in the coronary arteries can obstruct blood flow, increasing the risk of coronary heart disease.

Leukaemia: If, for any reason, there is an abnormal increase in white blood cells in the blood, symptoms of this disease may manifest. Excessive production of white blood cells in the bone marrow can lead to a decrease in red blood cells and platelets. The shortage of red blood cells can result in a lack of oxygen, causing the patient to feel weak, experience fatigue, and have difficulty breathing. The reduced production of platelets can lead to abnormal bleeding without any apparent injury. Although excessive white blood cells are produced, they are actually cancer cells, and often ineffective in defending against infections. Therefore, individuals with leukaemia are more susceptible to various infections caused by different microorganisms. In this way, each type of blood cell may not perform its normal functions properly, leading to symptoms of the disease. However, the symptoms may vary depending on the type of leukaemia.

11.4 Defence Mechanism of the Human Body

The visible structure of the human body and its various integrated processes are constantly observable, and we marvel at it. However, we do not see the defence mechanism that our body has developed to protect itself from the countless bacteria, viruses, and harmful substances in the surrounding environment. This defence system is not visible to us, but it is a remarkable mechanism. In this defence mechanism, there is an external physical barrier, similar to the way there is an extremely effective immune system that protects our body against diseases and viral threats in the diverse environment of our planet. Therefore, we can say that the defence mechanism of the human body is a sophisticated system composed of various biological components working to defend the body against diseases. This defence mechanism can be divided into three levels known as the first, second, and third defence lines.

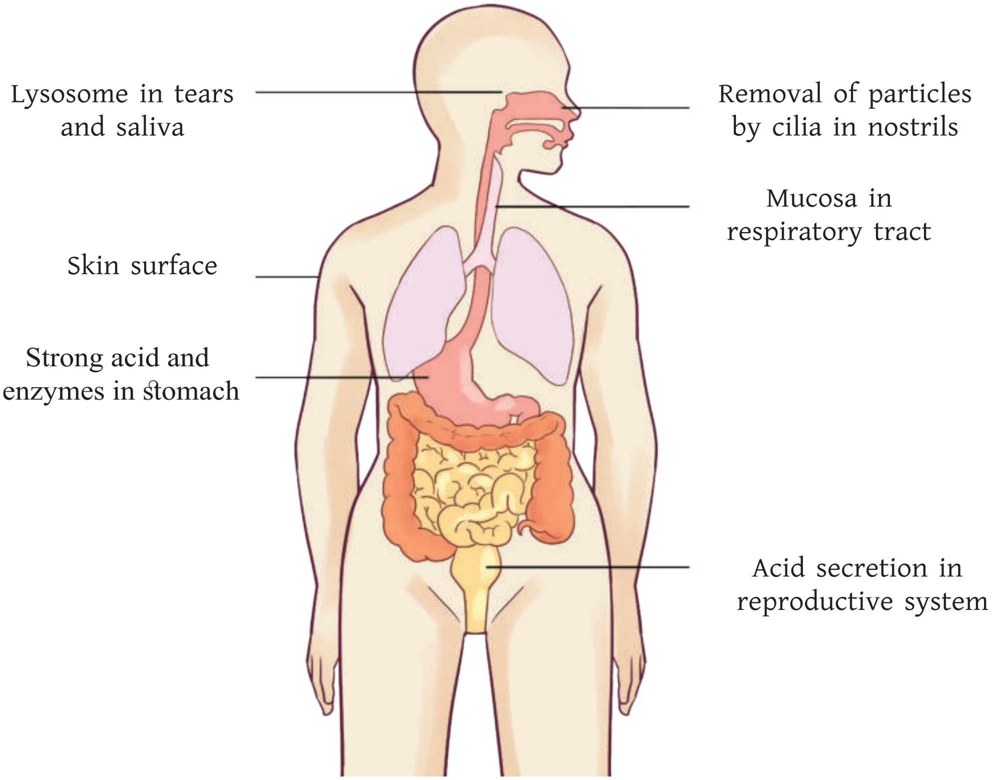


Figure 11.13: The first defence line of the human immune system

11.4.1 First Line of Defence

In the defence of the human body, the first line of defence creates a chemical and physical barrier to prevent the entry of any foreign particle or organism into the body. Since it does not specifically resist particular living organisms or particles, it is also known as a non-specific or non-specified defence mechanism. The essential components of this defence level are outlined below (Figure 11.13).

a. Skin: The skin is the largest organ of our body, serving as an air-resistant, waterproof, and impenetrable barrier for most substances. The skin plays a crucial role in the initial defence against invading bacteria, viruses, or fungi. With few exceptions of viruses, no disease-causing microorganisms can enter the body through intact skin. Beneficial bacteria always inhabit our skin, but harmful bacteria cannot survive there. Because the oils and sweat released from the sweat and sebaceous glands of the skin acidify it, creating an acidic environment where bacteria cannot thrive or reproduce. On the other hand, beneficial bacteria on the skin also play a role in controlling bacteria by producing acids and antimicrobial substances. Additionally, the destruction of bacteria by the desquamation of sweat and sebaceous glands also contributes to the skin's function as an antimicrobial organ in the human body.

b. Hair: The hairs inside the nose trap foreign particles and harmful substances, preventing them from entering the body.

c. Cilia: The open entry paths in the body are covered by a layer of mucus, and the cilia, keep foreign particles and microorganisms trapped in this sticky mucus. In the respiratory tract, the cilia, covered with mucus, continuously move like tiny hair, expelling external particles and microorganisms, keeping the entry pathways clear.

d. Cerumen or Ear wax: The substance resembling honey-brown wax that comes out of the ear is called cerumen. It acts as a protective barrier against infection by trapping debris, mucus, and microorganisms, preventing them from causing any harm to the hearing process in the ear canal.

g. Tears and Saliva: In tears and saliva, there is an enzyme called lysozyme that functions as a bacteriolytic agent. Tears moisten the eyes repeatedly, protecting them from external particles and microorganisms. Saliva keeps the mouth cavity moist and acidic, preventing the proliferation of bacteria on the oral mucosa and maintaining the dryness of the oral cavity's periphery to prevent easy damage by living bacteria.

h. Acid of Alimentary Canal: Despite various harmful microorganisms reaching the digestive system with our daily food and water intake, the powerful hydrochloric acid and proteolytic enzymes in the digestive tract prevent them from persisting, leading to their destruction.

i. Acid of Excretory-Reproductive System: The acidic environment in the organs associated with the excretory and reproductive systems acts as a barrier against the entry of any microorganisms that may attempt to enter the body. These microorganisms may get trapped in this acidic environment and later be expelled with urine or eliminated by phagocytes that come to engulf them. The beneficial bacteria in the genital tract produce lactic acid, maintaining an acidic pH, which, in turn, hinders the growth of harmful microorganisms and prevents their colonization.

11.4.2 Second Line of Defence

If the first line of defence is unable to prevent the entry of any microorganism or foreign particle into the body, then the second line of defence, known as the body's immune system, becomes actively involved in mounting a protective response against them. This defence level, composed of cellular and chemical defences, is also or non-specific, similar to the first line of defence. This defence mechanism can recognize the differences between the body's own cells and foreign particles, thus ensuring that only foreign microorganisms are destroyed without causing harm to the body's own healthy cells. The second line of defence includes the following defence mechanisms:

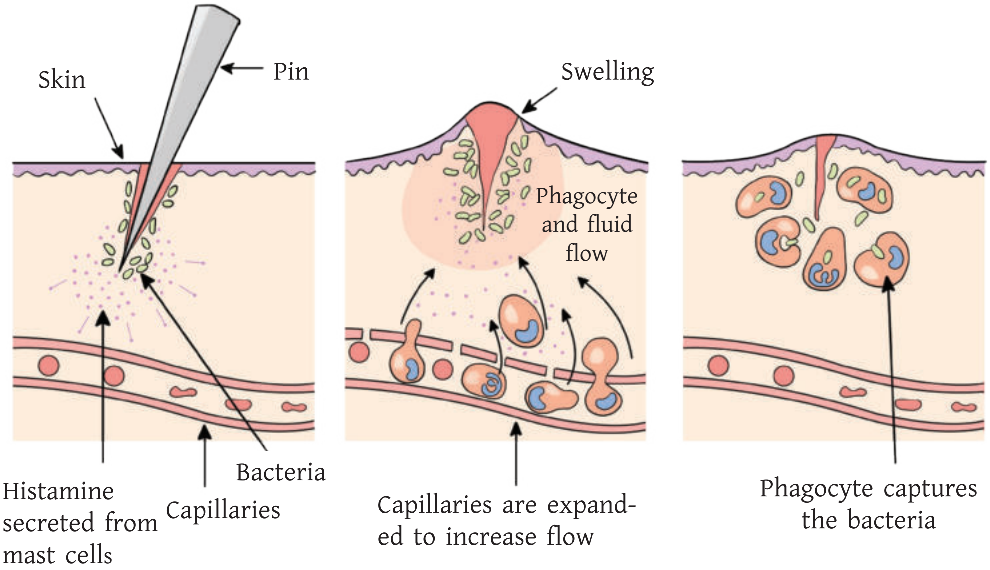


Figure 11.14: Inflammatory reaction

a. Phagocytes: Phagocytes are large white blood cells produced in the bone marrow that engulf and digest other cells or foreign particles, contributing to the body's defence mechanism. The two main types of phagocytic cells are neutrophils. When the body is invaded by microorganisms, neutrophils travel in the blood, while macrophages move into specific tissues, initiating the process of phagocytosis to engulf and digest the invading microorganisms. It acts as a scavenger by ingesting old blood cells, tissue fragments and cellular debris to clear waste.

b. Natural Killer Cells (NK Cells): Natural killer cells or NK-cells are a type of lymphocyte-like white blood cell that recognizes certain changes in the plasma membrane of tumour cells or cells infected by viruses. NK cells identify these cells in the plasma membrane and destroy them, contributing to the body's defence against tumours and virus-infected cells. NK cells create pores in the target cell's membrane during their attack, and to destroy the cell, NK cells enter the target cell's interior through these pores, releasing specific enzymes that lead to the destruction of the cell.

g. Inflammation: When our body is injured, the familiar response is inflammation (Figure 11.14). Inflammation occurs at the site of tissue damage, whether it is due to burns, chemical or physical injuries, or any type of infection-related damage. The affected area becomes red, warm, swollen, and painful. It is a form of external expression of our body's defence mechanism. When tissues are damaged, a chemical release occurs, resulting in increased blood flow to the injured area. This increased blood flow brings necessary immune cells and nutrients to the site of injury, promoting faster healing.

h. Complement System: The complement system is a group of over three dozen plasma proteins present in the blood that aid other immune mechanisms, earning it the name complement system. In their inactive state, these proteins remain dormant, but once one protein in the complement system becomes active, it activates other proteins. This activates a cascade of reactions that enhance both specific and nonspecific defence mechanisms, allowing for more rapid destruction of foreign cells. The complement system becomes attached to the microorganisms and thus identifies them, thus facilitating the arrival of immune cells and nutrients to the damaged area by promoting increased blood circulation.

i. Interferon: Interferon is part of the body's natural immune system. Produced as a small signalling protein in cells attacked by viruses, interferon is released as a response to viral infection to prevent viral replication. Through diffusion, interferon spreads to nearby healthy cells, integrates into their membranes, and stimulates these cells to produce more interferon. As a result, neighbouring cells become resistant to viral invasion, preventing the virus from attacking other healthy cells. Interferons, such as interferon-alpha and interferon-beta produced through genetic engineering, are used in medical treatment, particularly in combating viral infections like hepatitis B and C.

c. Fever: When the body's temperature is higher than normal, it is called fever, and it is a crucial weapon in the secondary defence mechanism. The hypothalamus in the brain controls the body's temperature alongside many other important functions. When macrophages, also known as white blood cells, recognize and attack viruses, bacteria, or foreign particles, the cells release a substance called pyrogen into the bloodstream. This pyrogen causes a metabolic change in the hypothalamus, determining a higher temperature for the body, which we refer to as fever. During fever, the body's metabolic rate increases, defence mechanisms and tissue repair are accelerated, and disease-causing microorganisms struggle to survive in the elevated temperature. When the action of pyrogen ceases, the body temperature returns to normal.

11.4.3 Third Line of Defence

The first and second defence levels are non-specific, meaning they do not specifically target or recognize particular pathogenic microorganisms or particles. In that respect, the third defence line is an exception. This is because this defence layer is specific to foreign pathogenic molecules entering the body organisms or particles. They not only destroy, but remember these specific harmful targets for life after the first attack. Any subsequent attacks can be responded to quickly and effectively. The third defence line is called ‘immune response’.

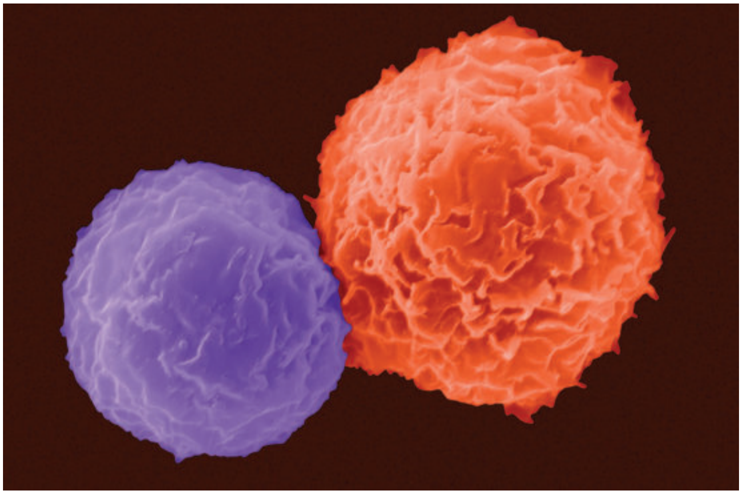


Figure 11.15: T-cell and B-cell

The characteristics of the third defence level are as follows:

(a) Target: This defence level can recognize and transform external microorganisms or particles into targets. Simultaneously, it has the capability to distinguish unhealthy or dead cells, similar to cancer cells from healthy cells within the body. To identify these targets, specific molecular markers on their surfaces need to be recognized. Once the target is identified, immune cells capable of destroying the pathogenic microorganisms are produced.

(b) Memory Cells: The most remarkable feature of the third defence level is its ability to retain memory of the infection in the form of memory cells. After the first encounter with a pathogenic microorganism and the establishment of a defence mechanism, memory cells are created. If the same microorganism attempts to infect the body again, the memory cells quickly recognize it, enabling a faster and more effective immune response. In this way, the third defence level actively works to strengthen the body's ability to resist specific external agents for years.

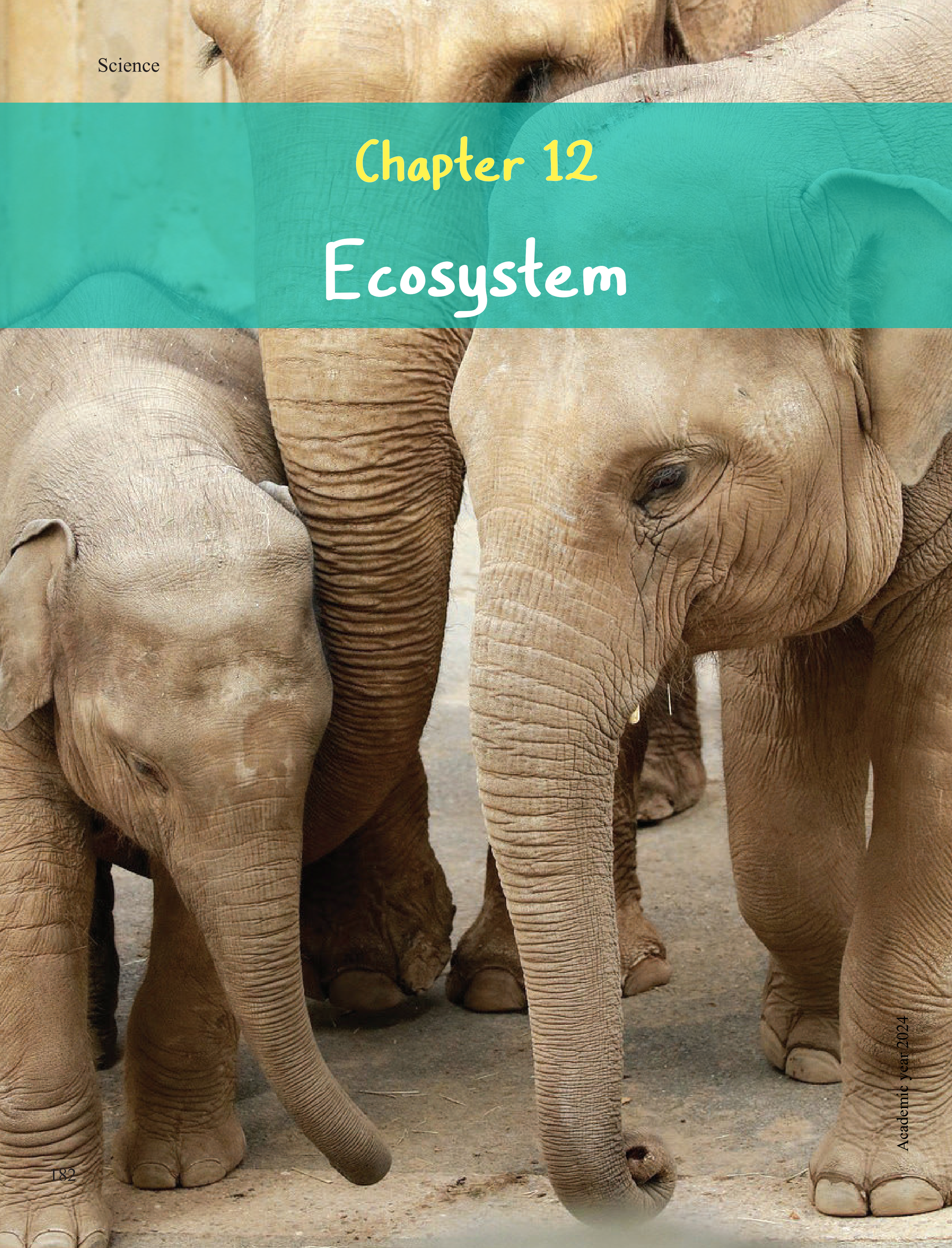
g) Comprehensive Defence: The third level of defence protects the entire body. The defence mechanisms against invading microorganisms are not limited to specific parts of the body but can be effective in any region.

(h) B-Cells: B-cells and T-cells (see Figure 11.15) are two crucial components of the human immune process. These white blood cells are intricately involved in the evolved immune response. Each B-cell can recognize specific antigens (unique atomic structures or markers on the surface of a microorganism), become active after recognition and begin to multiply. B-cells produce antibodies to resist the identified microorganisms, releasing them into the bloodstream. Additionally, some B-cells undergo transformation into memory cells after the defence, making them adept at recognizing and combating the same microorganism in subsequent encounters.

i) T-Cells: T-cells do not produce antibodies but regulate the immune process. Sometimes, they directly attack infected cells, while other times they activate NK cells or other types of immune cells. Similar to B-cells, these cells also generate memory cells, preparing for future infections.

Chapter 12

Ecosystem



Chapter 12

Ecosystem

In this chapter, the following topics are discussed:

- ☑ Coexistant Habitats of Various Organisms
- ☑ Ecology and Ecosystem
- ☑ Population Ecology
- ☑ Food Chains and Food Pyramids
- ☑ Water Cycle
- ☑ Oxygen Cycle
- ☑ Nitrogen Cycle
- ☑ Adaptations of Organisms to Different Environments

12.1: Coexistant Habitats of Various Organisms

Among the stars and planets in our familiar universe, the emergence of life has occurred only on Earth. Over billions of years, the life forms on Earth have evolved, diversified, and adapted to the ever-changing environment of this planet. There exists an unparalleled diversity in the living world surrounding us. This diversity leads to the classification of living organisms into countless species, each with its unique characteristics. While each species possesses its distinct traits, it is essential to recognize that no organism, whether plant, animal, microbe, or the natural environment, exists in isolation. Due to the interconnectedness of living entities, various habitats have evolved among different organisms, contributing to the ecological balance in the living world. We will shed light on this symbiotic relationship below.

For example, we often perceive green plants as self-sufficient entities since they produce their own food through photosynthesis. However, considering the environmental perspective, it becomes evident that green plants are not entirely self-dependent. Green plants depend on carbon dioxide for photosynthesis, which is released by other living beings through respiration. In the cycle of life, a flowering plant relies on an insect for pollination. Similarly, for the distribution of seeds, plants depends on animals and birds. Thus, plants, animals, insects, and all other living beings are dependent on and influenced by one another. For instance, green plants engage in photosynthesis, releasing oxygen, which in turn is used by the living world for respiration. Additionally, plants, animals, and various microorganisms affect each other in different ways through bacteria, fungi, and various types of microbes. The number of microscopic organisms residing in our bodies exceeds the number of cells we have, and they assist in our biological processes. In other words, the interconnectedness and interdependence are the keystones of life processes. The biological relationships existing among the memers of plant and animal kingdom are termed as symbiosis. Based on the interactions and transactions occurring between these symbiotic organisms, symbiosis can be classified into three categories—mutualism, commensalism, and parasitism.

Mutualism:

Mutualism refers to the symbiotic relationship where two organisms assist each other, and both benefit from the interaction. For example, bees collect nectar from flowers as their food source, and in the process of foraging, they aid in the pollination of flowers that results in the reproduction of plants. Many birds and bats consume fruits, and in the process of digestion, they disperse seeds through their droppings. This dispersal contributes to the germination of new plants. Ants protect a kind of insects known as aphids. Ants defend them from predators, and in return, aphids provide the ants with honeydew, a sweet liquid, serving as a food source (Figure 12.1). This mutualistic relationship between ants and aphids is beneficial for both parties.

Figure 12.1: Mutualism - (Left) Bee pollinating a flower, (Right) Ant and Aphid.

Commensalism:

In commensalism, one organism benefits, while the other is neither harmed nor benefitted.

For example, the epiphytic plants anchor themselves in the soil with the help of their roots and ascend on other larger plants. They spread over other trees to capture more sunlight without causing any harm to the host tree. Epiphytes gather nutrients from the air or from hanging on other trees, but they do not inflict any damage to the host. Small fishes called Remoras attach themselves to larger marine animals like sharks, using a specialized suction disc (Figure 12.2). Without exerting any effort itself, the remora fish relies on the assistance of the shark to navigate beneath the sea and survives by consuming the leftover food. In this commensalism, there is no harm to the host; however, the remora fish derives significant benefits from the shark.

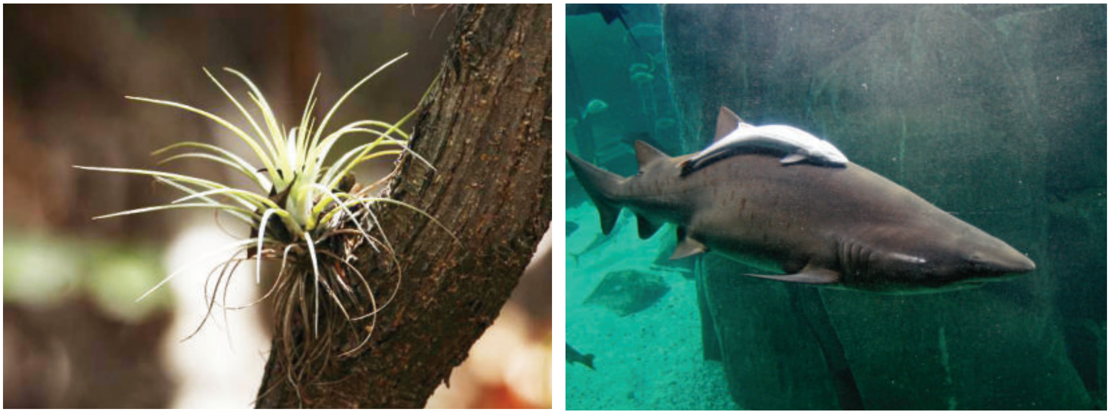


Figure 12.2: Commensalism: (left) Epiphytic plants (right) Shark and Remora fish

Parasitism:

In commensalism, one organism benefits, while the other is neither harmed nor benefitted. For example, the epiphytic plants anchor themselves in the soil with the help of their roots and ascend on other larger plants. They spread over other trees to capture more sunlight without causing any harm to the host tree. Epiphytes gather nutrients from the air or from hanging on other trees, but they do not inflict any damage to the host. Small fishes called Remoras attach themselves to larger marine animals like sharks, using a specialized suction disc (Figure 12.2). Without exerting any effort itself, the remora fish relies on the assistance of the shark to navigate beneath the sea and survives by consuming the leftover food. In

Figure 12.3 : Parasitism: Dodder and Host Plant

this commensalism, there is no harm to the host; however, the remora fish derives significant benefits from the shark.

12.2 Ecology and Ecosystem:

Ecology refers to the study of the relationship that exists between the living world and its surrounding environment. On the other hand, an ecosystem is a region where the resident plants and animals, along with the abiotic components of that region—such as soil, water, air, and sunlight—interact in a kind of symbiosis. Both the abiotic and biotic components are the fundamental basis of ecology.

12.2.1 Ecosystem

In our environment, everything, whether living and non-living, or in any kind of physical state, collectively forms Earth's diverse ecosystems. Living organisms actively extract essential elements from the non-living world to live their lives. After death, their bodies decompose and merge with the environment, returning all acquired elements back to the inanimate surroundings. Green plants intake carbon dioxide from the air and asorb water from the soil, to produce their main food carbohydrates through the process photosynthesis, while releasing oxygen. A significant portion of the needed oxygen for the respiration of the entire living world is produced through the process of photosynthesis. Both green and non-green plants absorb some mineral salts as nutrients from the soil or water. Herbivorous animals consume various parts of plants, while carnivorous animals at different levels consume herbivores or other smaller carnivorous animals as their food. The waste products of all organisms end up in the environment and decompose. Additionally, after death, the decomposition of plant and animal bodies by decomposers, including bacteria and other microorganisms, releases elements back into the environment. This natural recycling process maintains the balance in the natural environment.

By now, you have learned that in the natural environment, there is an intricate interplay of energy and matter among plants and animals—the two types of living organisms—and the inanimate substances. This interaction is termed as ecology. Any region on Earth, exhibiting such interactions between living organisms and their abiotic components like soil, water, air, and sunlight, is referred to as an ecosystem. Therefore, an ecosystem is any area on Earth where there is a continuous interaction between living organisms and their environment.

Elements of Ecology:

The formation of any ecosystem in a particular place occurs through the interaction of three main components: the community of organisms, the inanimate substances in the environment, and the physical surroundings. In each of these three primary elements, various types of small elements (Figure 12.4) are present, and among them, living elements always exhibit the highest diversity.

Non-living Elements:

The non-living substances in the environment create habitats for living organisms, contribute to oxygen production for respiration, and supply some nutritional elements. In ecology, all non-living elements can again be divided into two categories: inorganic and organic.

(a) Inorganic Substances: Water, air, and minerals present in soil, that is, substances that did not originate from any living organism but already existed in the—are considered inorganic elements of ecology. Examples include calcium, potassium, iron, nitrogen, oxygen, carbon dioxide, etc.

(b) Organic Substances: Substances derived from the bodies of plants and animals, or the organic remains of living organisms, are termed as organic elements in ecology. These are commonly known as humus. Humus include urea, various plant and animal cells, tissues, organs, etc. Organic substances are more nutritious for plants, so organic fertilizers are often used in plant cultivation. Many animals also prefer soil rich in humus.

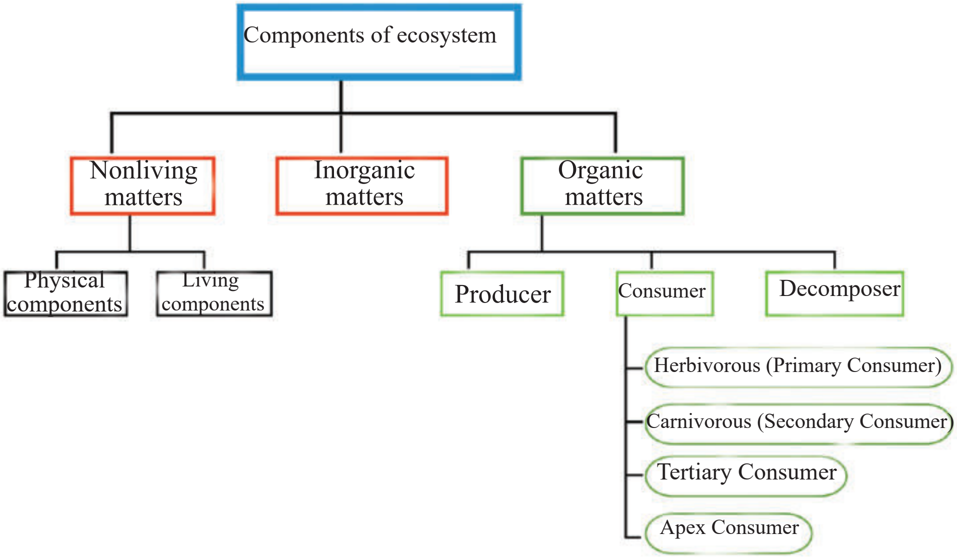


Figure 12.4 : Elements of Ecosystem

Physical components:

The physical elements of an ecosystem are influenced in various ways by factors such as the amount of sunlight, temperature, the quantity of water vapor in the air, air pressure, air circulation, depth from the Earth's surface or sea surface (for regions below the soil or water surface), and altitude. When these elements combine, they create the weather, climate and hydroclimate of a particular region. All these elements are considered as the physical components of any ecosystem.

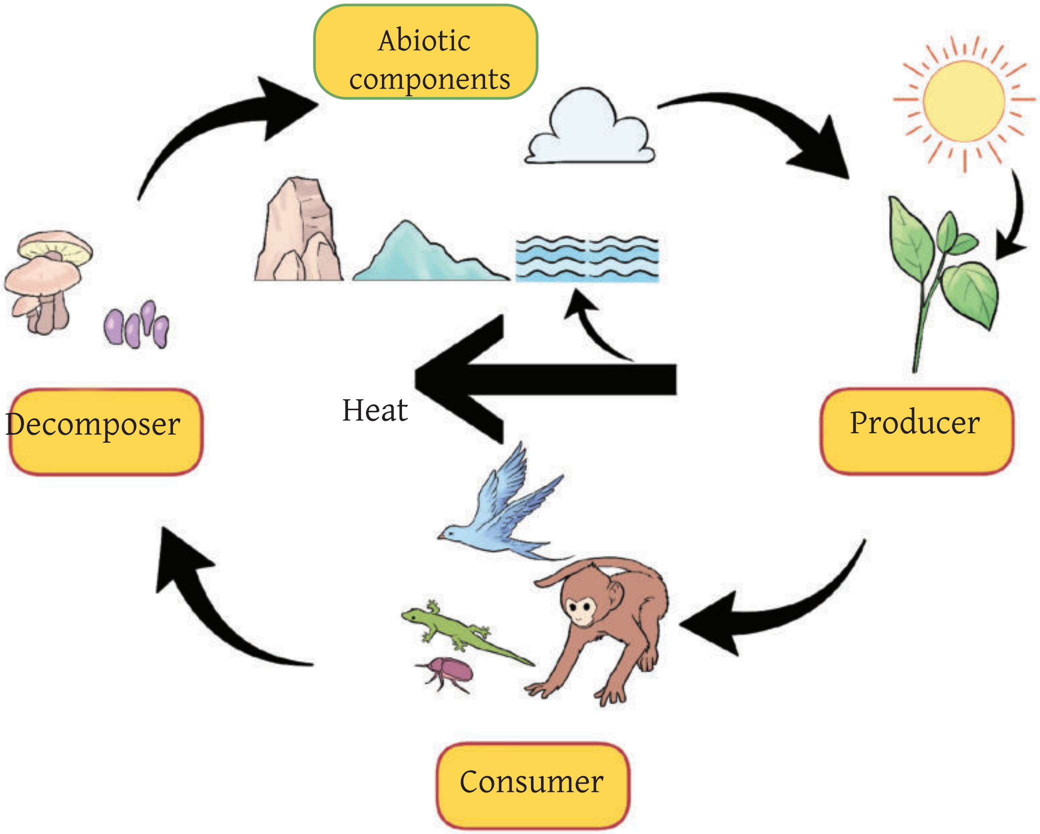


Figure 12.5 : Living Components of Ecosystem

Living components:

Living organisms are the active components of an ecosystem. They bring about various changes in the environment through their activities. The living components of the environment can be primarily categorized into three types: producers, consumers, and decomposers (Figure 12.5).

(a) Producer: Green plants gather carbon dioxide from the air and water from the soil to produce their primary food, carbohydrates, through the process of photosynthesis. During this process, plants release oxygen as a byproduct. Therefore, photosynthesis is the production process in the ecosystem, and primarily green plants are the producers. These producer organisms are called autotrophs because they can produce their own food and do not depend on other organisms.

(b) Consumer: No animal can directly produce food from the inorganic substances in the environment. They depend directly or indirectly on green plants for their food. That is why animals are called consumers. Animals that directly consume plants as their food source are called herbivores. They are also known as primary consumers. Grasshoppers, chickens, cows, goats, deer, etc., are examples of primary consumers.

Animals that consume herbivores as their food source are termed secondary consumers. These are carnivorous animals. Examples of these include frogs, foxes, tigers, etc.

Organisms that primarily feed on other animals or secondary consumers are also knows as carnivores. They are considered tertiary or, in some cases, apex consumers in the food chain. Snakes, peacocks, tigers, and other similar species fall into this category.

A specific category of consumers prefers consuming the flesh or carrion of dead animals over living prey. Crows, vultures, foxes, and hyenas fall into this category. They are called scavengers as they contribute to maintaining environmental cleanliness by consuming dead bodies or carrion. It should be mentioned that in the ecosystems, there are organisms that play multiple roles as consumers at different trophic levels. For example, humans are omnivores, consuming both plant-based and animal-based food sources.

(c) Decomposer: Microorganisms such as bacteria and fungi, among other extremely small living organisms, obtain their nourishment from the remains of plants, animals, and their waste products. As a result, these waste materials undergo decomposition and mix with the soil or water. The substances assimilated in this process once again become potential nutrients for plants. Therefore, these microorganisms are referred to as decomposers or transformers.

12.3 Population Ecology

The term ‘population’ refers to the number of a specific species in a particular area, and population ecology elucidates the relationship of this number with the environment of that area. Population ecology investigates how populations grow, decline, or remain stable over time and explores the reasons behind these trends. It also sheds light on how the population of an organism affects the ecosystem of that region.

Population ecology encompasses four main elements: size, density, number of individuals of a species, dispersion, and demography.

(a) Size: The total number of a specific species in the area denotes the size of the population.

(b) Density: Dividing the total number of individuals of a specific species by the size of the area gives the density of the population.

(c) Dispersion: Dispersion elucidates how the population of a species is spread throughout an area. Dispersion can occur in three ways (Figure 12.6): random, uniform, and clumped.

Random: When individuals of a species are found spreaded randomly in an area, it is called random dispersion. For instance, seeds from a dandelion flower scattered by the wind can germinate anywhere in the area, illustrating random dispersion.

Uniform: If organisms of a species are somewhat uniformly spaced from each other in an area, it is termed uniform dispersion. Penguins are an example of organisms exhibiting uniform dispersion.

Clumped: When many individuals of a species form groups in an area, it is referred to as clumped dispersion. The herd of elephants is an example of clumped dispersion.

(d) Demography: The proportional rate of each age group in a population is termed as demography.

Figure 12.6 : Random, Uniform and Clumped Dispersions of Species

Examining the growth rate of a population in a region is a fundamental aspect of population ecology. The growth rate of a population depends on four different factors: birth rate, death rate, immigration rate, and emigration rate. Considering a region inhabited by a population of Sparrows, we observe that every year, some Sparrows are born, and due to various reasons, some birds die. If the birth rate exceeds the death rate, then the population of

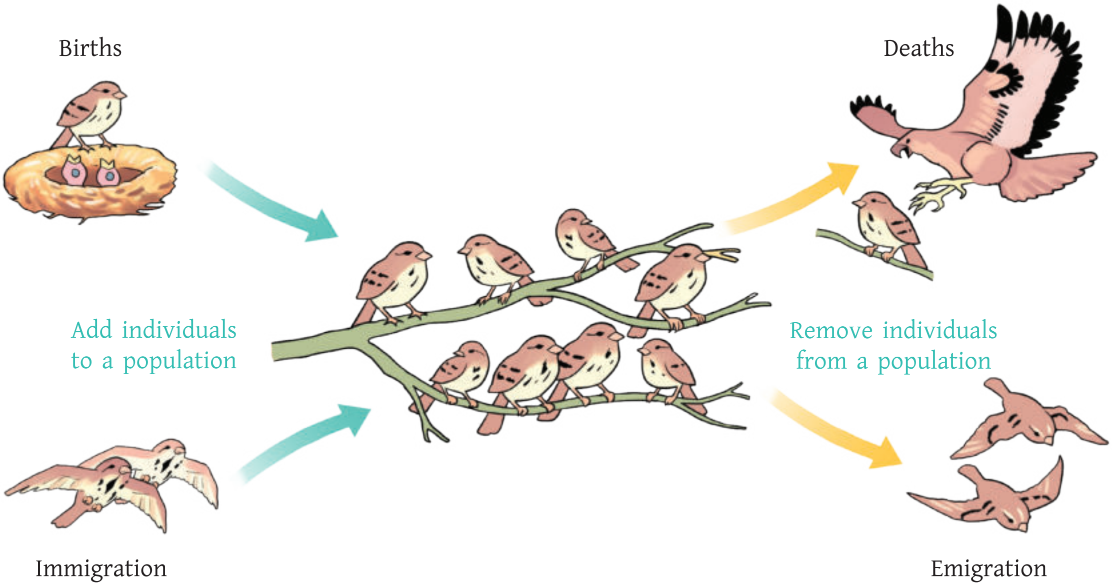


Figure 12.7 : The population of organisms depends on birth rate, death rate, immigration rate, and emigration rate.

Sparrows in that area will inevitably increase. Immigration and emigration rates, in addition to birth and death rates, affect population growth. Some birds in search of a better habitat might leave the area, causing a decrease in the population, while birds from other areas may arrive, contributing to an increase in the population. If the number of immigrations exceeds the number of emigrations, then the bird population in that area will increase (Figure 12.7).

Before delving deeper into population ecology, it is necessary to acquaint ourselves with two streams of reproduction of our biological lineage: r and K selection. Organisms that produce a large number of offspring but invest little care in their upbringing are termed 'r-selected' organisms. Examples include insects and fish. On the other hand, organisms that emphasize quality over quantity in their offspring production, meaning they invest more care in a smaller number of offspring, are categorized as 'K-selected' organisms. Humans and other large mammals are examples of K-selected organisms. K-selected organisms thrive when the environment is favorable and stable.

We can explain the 'K-selected' and 'r-selected' organisms by the likelihood of survival throughout their life span. For instance, large mammals like humans or elephants have quite a small number of offspring, and they invest a lot of time and energy in nurturing their offspring to ensure their survival. Consequently, the mortality rate of their offspring is low, and a significant portion of them can reach adulthood (Figure 12.8). On the other hand, 'r-selected' organisms produce a plethora of offspring but invest little time or energy in their upbringing. These organisms experience a higher mortality rate at the beginning of their

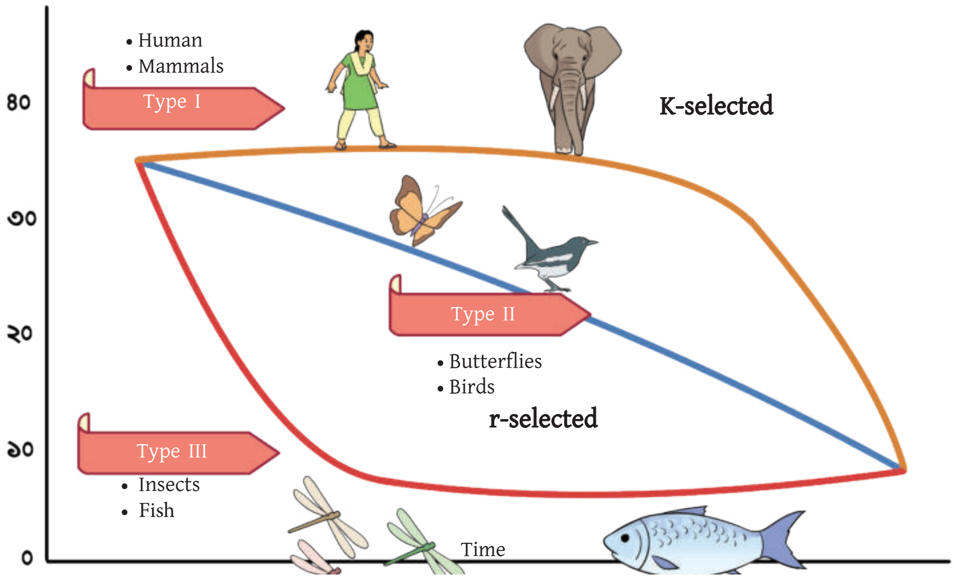


Figure 12.8: ‘K-selected’ and ‘r-selected’ organism`s survival throughout their life span

life cycle due to various reasons. However, as they mature, some of them begin to survive. Various insects and fish fall under this category. Considering the probability of survival in their life cycle, ‘K-selected’ organisms are termed as Type I, and ‘r-selected’ organisms are termed as Type III. Between these two life strategies, there is another life strategy known as Type II, where the probability of death is equally distributed throughout the entire life. Some birds or rodents fit into this category.

The population growth of a particular species in a specific area depends on several factors, including (1) how quickly the organism can become reproductive, (2) how fast it can give birth to the next generation, (3) how many times it can reproduce, and (4) how many offspring it can produce each time.

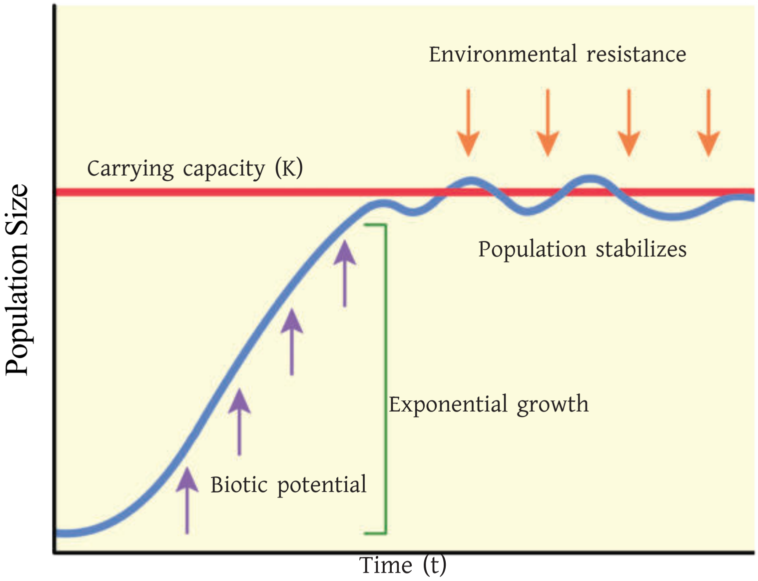


Figure 12.9 : Carrying capacity of organisms

If there is no obstacle or stress factor from the environment, the population growth rate can increase geometrically. However, population growth is often limited to an extent due to the shortage of light, air, space, and nutrients in the environment after reaching a specific numerical value. After achieving equilibrium between birth and death rates, the population stabilizes at a certain level, and this stable number for a region is the carrying capacity of that particular organism. In a specific area, the term ‘carrying capacity’ refers to the maximum number of living organisms that a species can sustain (Figure 12.9). You can infer that the carrying capacity for a particular organism in a specific area depends on several factors. However, it is generally divided into two categories: factors dependent on population density and those not dependent on population density. Food, water, or habitat scarcity falls under factors dependent on population density, while natural disasters, hurricanes, climate impacts, etc., are examples of factors not dependent on population density.

12.4 Food Chain and Energy Pyramid

12.4.1 Food Chain:

In any ecosystem, green plants take the first step as producers among the biotic components. If they fail to produce food, herbivores would face a food crisis and perish, and in turn, if herbivores are absent, carnivores would fail to find their prey and could die. When the flow of food energy starts from producers and moves through different trophic levels among consumers, it is called a food chain (Figure 12.10).

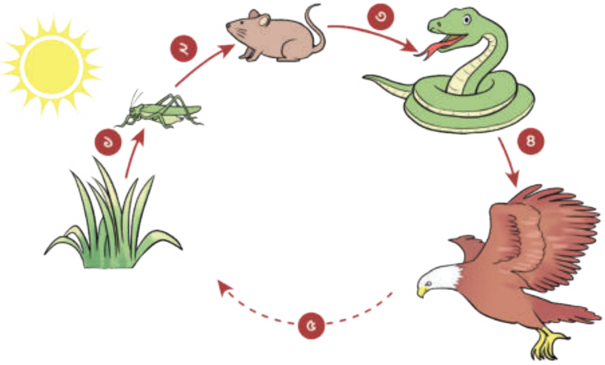


Figure 12.10 : Food Chain

As an example, consider the green grass in a field as the producer. The grasshopper survives by consuming a parts of the grass. The rats considers the grasshopper as its food, while the snake preys on the same rats. If the snake is not significantly large, a hawk will then eat the snake. In this case, the food chain can be represented as follows:

Grass	→	Grasshopper	→	Rat	→	Snake	→	Hawk
(Producer)		(Primary Consumer)		(Secondary Consumer)		(Tertiary Consumer)		(Apex Consumer)

Note that after the death of a hawk, bacteria, fungi, and other microscopic organisms or microorganisms, obtain their food from the carcass of the hawk. As a result, the body decomposes and mixes with the soil or water. This, in turn, becomes food for grass or other plants, completing the cycle.

Different ecosystems can have different types of food chains. Such as, predator-prey food chains, parasitic food chains, and saprophytic food chains.

(a) Predator Food Chain: The food chain where the primary consumers, being the smallest in size at the first trophic level, are preyed upon by consumers gradually at higher levels, is called a predator food chain. The food chain described above is an example of a predator food chain.

(b) Parasitic Food Chain: In the parasitic food chain, parasitic plants and animals generally obtain nourishment from larger organisms. In this chain, the first step of the food chain may not always involve green plants.

Human → Mosquito → Dengue Virus

(c) Saprophytic Food Chain: In this type of food chain, nutritional elements are transferred from the decomposed or decayed remains of living organisms towards various microorganisms. Therefore, this type of food chain mainly involves dead organisms and decomposers. For instance:

Dead Plant → Fungus → Bacteria

Since they lack producers, parasitic and saprophytic food chains are dependent on one or more trophic levels in predator food chains. Therefore, we can surmise that all food chains in ecosystems fundamentally rely on the efficiency of the photosynthesis process of the green plants in nature.

12.4.2 Food Web

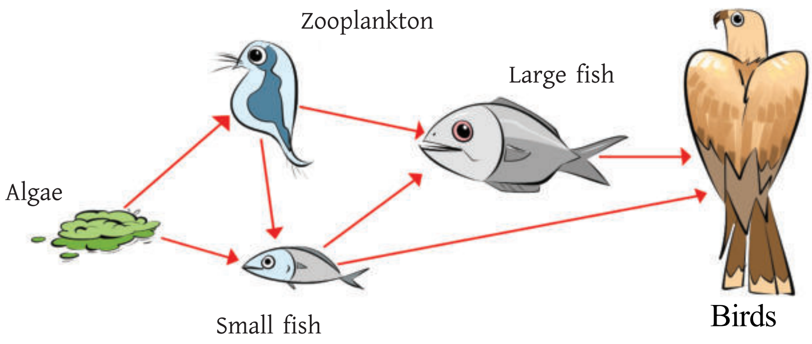


Figure 12.11 : Food Web

In most cases, it can be observed that in the food chain of an ecosystem, the same consumer can occupy different levels. In such cases, several food chains interconnect to form a network resembling a web, known as a food web (Figure 12.11). This phenomenon occurs in both terrestrial and aquatic environments, as illustrated more in the adjacent figure.

In the above figure, it can be seen that algae or plankton directly serves as food for zooplankton and small fish. Zooplankton serves as food for both small and large fish. Large fish, in turn, consume small fish. Birds of prey, such as hawks, prey on both small fish and large fish unless the latter is considerably larger. Here, five food chains have been formed for both terrestrial and aquatic organisms. In reality, food webs in some ecosystems can be even more intricate than depicted in this example.

The five food chains in the above food web are as follows:

(a) Plankton → Small Fish → Birds of Prey

(b) Plankton → Zooplankton → Large Fish → Birds of Prey

(c) Plankton → Small Fish → Large Fish → Birds of Prey

(d) Plankton → Zooplankton → Small Fish → Large Fish → Birds of Prey

(e) Plankton → Zooplankton → Small Fish → Large Fish → Birds of Prey

To understand how a food web in a forest ecosystem might look, refer to Figure 12.12.

12.4.3 Nutrient Flow in Ecosystem:

Through the concept of food chains, we have gained an understanding of the steps involved in obtaining food for various organisms' life processes. However, we can also view this process as a flow of nutrients. For example, plants absorb inorganic substances and prepare food through photosynthesis. The plants utilize some of these food for their own needs, storing the remaining portions in their bodies. Herbivores consume these plants, and carnivores, in turn, feed on herbivores. After the death of these organisms, decomposers

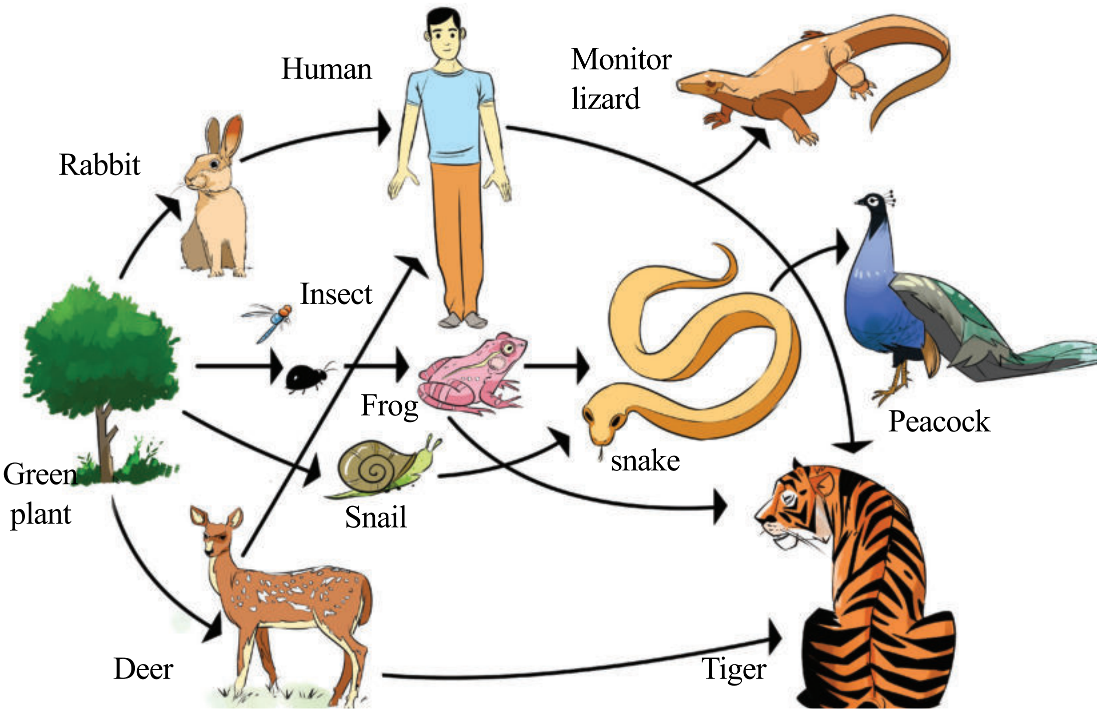


Figure 12.12 : Food Web in a Forest Ecosystem

utilize their remains as food, transforming them into inorganic substances and return them back to the environment. Green plants absorb these inorganic substances again, continuing the cycle. This cyclic flow of nutrients is called nutrient flow. The flow of nutrients through food chains is a vital feature of ecosystems.

Energy Flow in the Ecosystem:

In any ecosystem, the primary source of energy is the sun. At most, only 2% of the sunlight reaching the Earth is utilized in photosynthesis by green plants. The primary consumers of the ecosystem comprises herbivores, which consume the leaves, stems, flowers, fruits, seeds, or roots of green plants to sustain life. Carnivores, feeding on herbivores, constitute the second level. In this way, chemical energy is transferred from the first to the second trophic level. Similarly, energy from the second trophic level is transferred in the form of food to the third trophic level. If a higher trophic level consumes the third trophic level as food, the same process results in the transfer of energy to the highest trophic level. The transfer of energy through different trophic levels is referred to as a food chain. A typical food chain consists of 4-5 steps or levels.

Each step in the food chain is called a trophic level. During the transfer of energy between trophic levels, a significant amount of energy is converted into heat, which is not useful for consumption in the next trophic level. Therefore, the smaller the food chain, the more efficiently the energy is transferred from one level to another. In any ecosystem, only about 10% of the energy at one trophic level can be transferred to the level above it. The remaining 90% is released as heat into the environment or is partially unused.

The energy acquisition process of all organisms ceases after death. At that point, the accumulated chemical energy in the dead body is broken down by decomposers, and the inorganic matters or energy is returned to the environment. This energy, stored among various inanimate substances in the environment, is then once again utilized by plants. In this way, the natural flow of energy in the ecosystem continues through the medium of food chains.

12.4.4 Concept of Energy Pyramid:

You have already learned that in an ecosystem, only 10% of energy is transferred from one trophic level to another, and the rest is lost as heat into the environment. Consequently, the total energy decreases as it moves to the next trophic level. Due to this, when the transfer of energy from lower to higher trophic levels is arranged consecutively, a pyramid-shaped figure is obtained, known as the food pyramid or energy pyramid (Figure 12.13).

The flow of energy in this pyramid is always unidirectional; it cannot be reversed. Approximately 90% of the energy is lost or becomes unusable at each step. This progressive loss of energy confines the shape of the food chain to 4 or 5 steps. The longer the food chain, the less energy will be available at the upper trophic level, and at some point, no energy will remain.

In addition to the transfer of energy, the pyramid of energy can also represent the number of

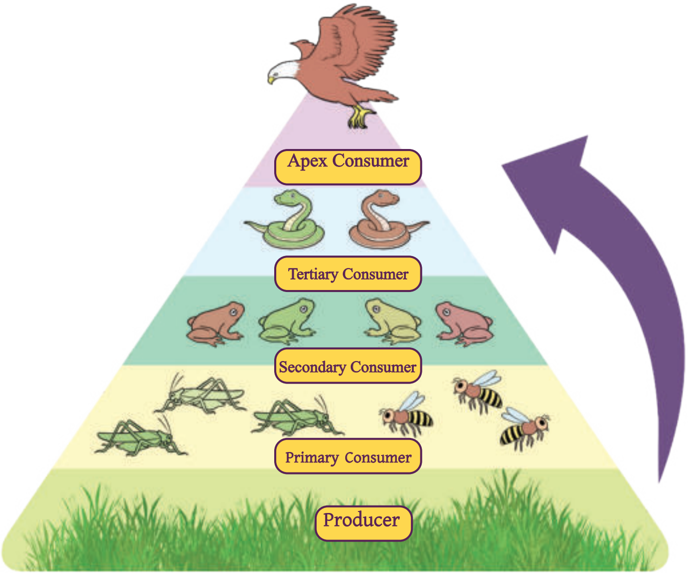


Figure 12.13 : Energy Pyramid

organisms or biomass in an ecosystem, shedding light on various aspects of the structure of the ecosystem.

12.5 Water Cycle

The water cycle refers to the mutual exchange of water between the atmosphere, the Earth's surface, and the underground water beneath the Earth's surface (Figure 12.14). Behind the dynamics of life on Earth, there is a significant role played by water, and the Earth's water cycle contributes to the development, evolution, and adaptation necessary for life. As you all know, water can exist in three states: solid, liquid, and gas, and it undergoes changes in its state through the exchange of energy. Not only that, but due to approximately three-fourths of the Earth's surface being covered with water, it functions as a storage of vast amount of thermal energy. Consequently, the water cycle, driven by the exchange of energy with water, plays a crucial role in maintaining the stability of the Earth.

You know that in the water cycle, water undergoes changes in its solid, liquid, and gaseous states. However, this change is a physical transformation. Therefore, there is no change in the total amount of water or the number of water molecules in the water cycle. In the water cycle, processes such as vaporization, liquidation, condensation, sublimation, and deposition occur to facilitate the transformation of water in its different states. Let's briefly discuss the processes involved in various stages of the water cycle.

Water Vapor in the Atmosphere

Vaporization: The sun is the source of all energy on Earth, supplying the necessary energy for the vaporization of water on the Earth's surface. The liquid water on the Earth's surface absorbs thermal energy from the sun's light, undergoes vaporization, and transforms into vapor, rising into the atmosphere.

Sublimation: Ice or snow typically transforms into water when they melt, but under low air pressure and dry conditions, sublimation can occur to transform ice or snow directly to vapor. Considering energy expenditure, this process consumes less energy, making it feasible for ice on mountain peaks or glacier regions to undergo sublimation and enter the atmosphere as vapor.

Transpiration: Besides vaporization and sublimation, plants release a significant amount of aqueous vapor into the atmosphere through the transpiration process, primarily occurring through their leaves.

Water on the Earth's Surface:

Condensation: Water vapor in the air rises and cools, undergoing condensation in small droplets and forming ice particles. Eventually, these gather together and transform into clouds, which circulate in the sky.

Precipitation: Aggregated small water droplets converge and transform into large water droplets in a cloud at some point, falling to Earth as precipitation or rain. However, for the formation of rain droplets, they must accumulate on particles of dust or other substances. When the temperature drops sufficiently, these water droplets transform into ice particles, resulting in snowfall or hailstones on Earth.

Flow of Water: A part of precipitation that does not infiltrate the soil. It enters rivers and streams, flowing over the Earth's surface and eventually accumulating in the sea. In some places, the wind carries some water vapor as clouds over mountain ridges. The clouds cool there, forming snow If the rate of sublimation of water exceeds the rate of condensation in the mountain region or a mountain peak during the uplift process, then the formation of frost occurs. In the warm season,

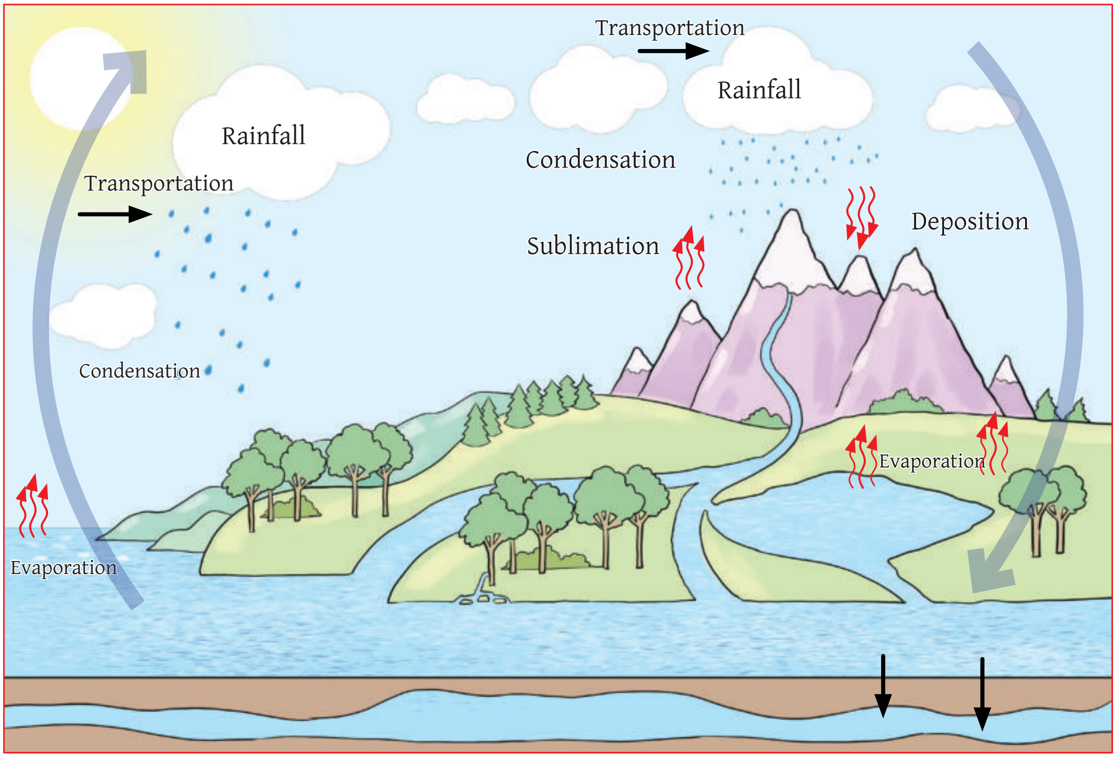


Figure 12.14 : Water Cycle

under the heat of the sun, the ice melts into water and descends from the mountain. Small rivers are formed on the slope of the mountain this way. These small rivers then cascade down to create larger rivers on the plains. Finally, the water flows to the sea.

Water in the Subsurface:

Infiltration: The process by which rainwater penetrates the soil and enters the subsurface of Earth is called infiltration. The amount of water that accumulates in the subsurface depends on how deep the water penetrates and the type of soil it enters, as well as the surface characteristics of the soil. While rocky areas may retain less water, muddy soil can hold more water. Water that infiltrates the Earth's surface can form an aquifer below the soil.

So, you can understand that water from the Earth's surface goes through the phases of water vapor, clouds, precipitation, snow or hail, and finally, this precipitation and snowmelt flow into rivers and ultimately reach the sea. In this way, the water cycle perpetuates. The specific starting or ending points of these phases mentioned are not fixed, as the water cycle is constantly occurring without any interruption.

Significance of the Water Cycle

The significance of the water cycle is immeasurable. It has a significant impact on the climate. For example, if the environment is not cooled down through the process of water vaporization, then the Earth's temperature can become intolerable due to the greenhouse effect. Additionally, the water cycle purifies the air. For instance, during the formation of raindrops, small water particles gather on dust particles, which are then brought down to the Earth's surface from the atmosphere. Not only that, but the water cycle also helps in purging the atmosphere of pollutants, even including viruses and bacteria, through rainwater runoff.

12.6 Oxygen Cycle

We all know that 78% of the air is nitrogen, 21% is oxygen, and the remaining 1% is made up of other gases. However, this amount of oxygen was not always present in the Earth's atmosphere. Approximately 4.6 billion years ago, cyanobacteria started photosynthesis on Earth, producing oxygen, and around 300 million years ago, the current levels of oxygen

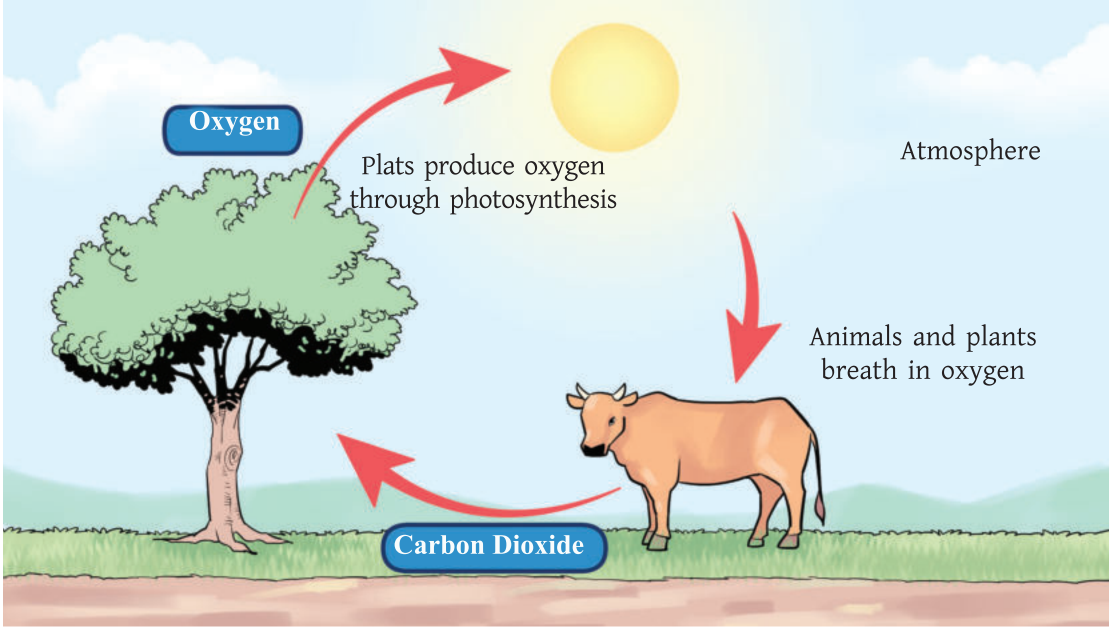


Figure 12.15 : Oxygen Cycle

in the Earth's atmosphere were reached. Most organisms on Earth respire oxygen, meaning oxygen plays a fundamental role in sustaining life on Earth. The oxygen cycle (Figure 12.15) is a biochemical cycle, and through this cycle, the amount of oxygen on Earth is maintained at a relatively constant level. This cycle extends not only through the atmosphere but also throughout the Earth's biosphere and lithosphere. In fact, there is much more oxygen in the lithosphere than in the Earth's atmosphere.

The oxygen cycle can be divided into three parts. In the first step, all green plants on Earth undergo photosynthesis, absorbing carbon dioxide gas from the atmosphere and releasing oxygen as a byproduct while creating food for themselves. In the second step, all respiring organisms take in oxygen for their respiration. In the third step, all living organisms release carbon dioxide during respiration, which is then used again by plants for photosynthesis. This process helps maintain a stable level of oxygen in the atmosphere. It's noteworthy that the amount of oxygen released from terrestrial plants is almost equal to that of the amount released by photosynthesis by underwater organisms. Some oxygen is also exchanged between the Earth's atmosphere and the lithosphere.

Oxygen is the most crucial component of the Earth's atmosphere. This gas is used for the following purposes:

The Significance of the Oxygen Cycle:

1. Organisms take in oxygen through respiration and generate energy for themselves through the combustion of food in the presence of oxygen.

2. Burning activities, such as in cooking ovens, in vehicles, in factories, and in many other processes, involve the combustion of fuels to produce energy, and oxygen is necessary in all these combustion processes.

3. Aquatic organisms in water absorb dissolved oxygen, which is essential for their life processes.

4. Oxygen is utilized in the process of decomposition of organic substances.

12.7 Nitrogen Cycle

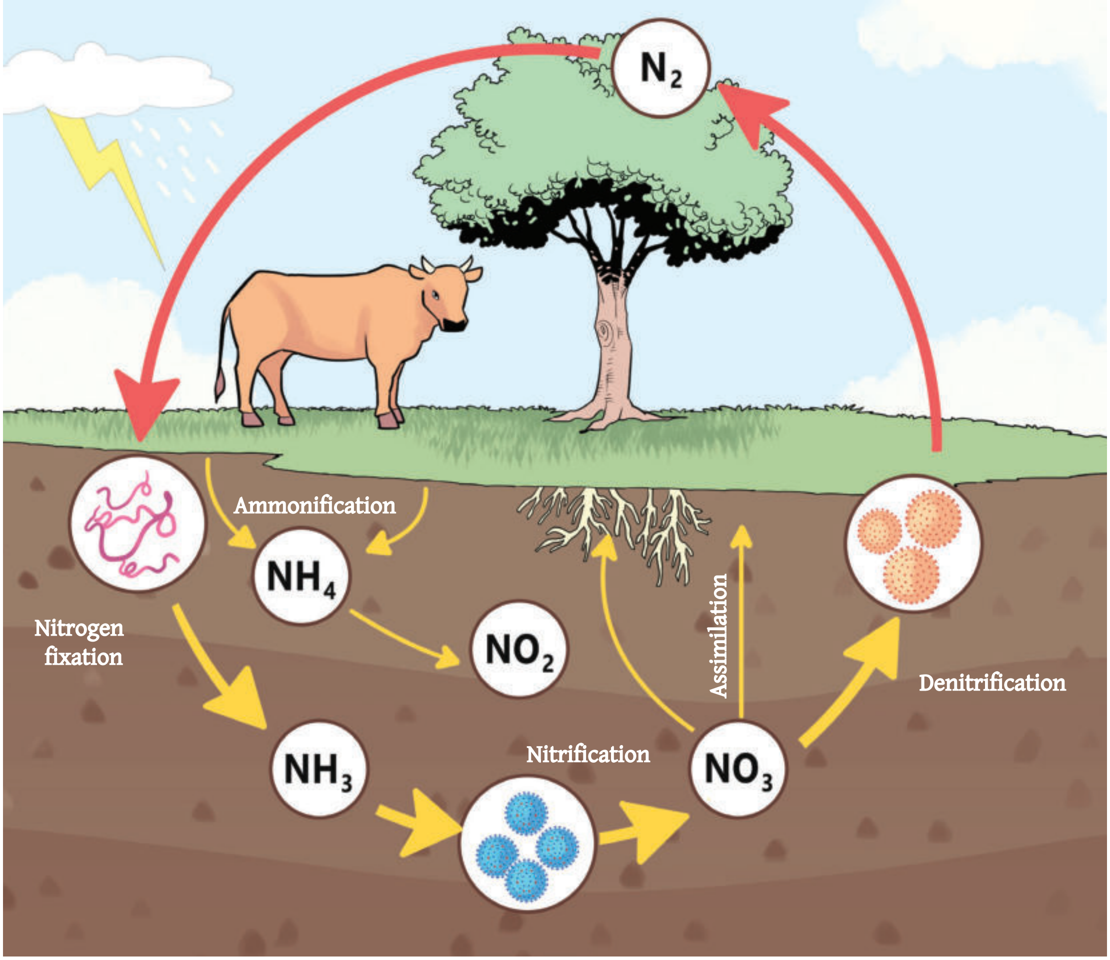


Figure 12.16 : Nitrogen Cycle

The nitrogen cycle (Figure 12.16) is another important component of Earth's ecosystem. Nitrogen is an essential nutrient for living organisms, but despite its abundant presence in the atmosphere, no living animal or plant can directly utilize it. The nitrogen cycle is a biogeochemical process that transforms inert nitrogen gas into a form that is usable by living organisms. Through this cycle, nitrogen gas from the atmosphere enters the soil and, at the end of the cycle, returns to the atmosphere. Several active processes within the nitrogen cycle are discussed below.

Nitrogen Fixation: The nitrogen cycle begins with nitrogen fixation, where specific bacteria convert atmospheric nitrogen present in the air into ammonia. These bacteria reside in the soil and form a symbiotic relationship with plants.

Nitrification: In this process, ammonia is first transformed into nitrite and then into nitrate ions. Once converted to nitrate, plants can easily uptake it as a nutritional component.

Assimilation: In this process, plants take up nitrate from the soil and utilize it to form amino acids and other molecules composed of nitrogen, essential for the synthesis of DNA and proteins. Animals obtain their necessary nitrogen from plants.

Ammonification: When plants or animals die, bacteria and fungi decompose their remains, converting them back into ammonia. Just as ammonia is transformed to nitrate in nitrogen fixation, in ammonification, ammonia is converted back to nitrate.

Denitrification: In areas with low oxygen levels, denitrifying bacteria break down nitrate, releasing nitrogen back into the atmosphere.

It is worth mentioning that the excessive use of chemical fertilizers has led to an increase in nitrate levels in the soil, contributing to a form of environmental pollution. Therefore, proper regulation of the nitrogen cycle has become urgent for human well-being.

Significance of the Nitrogen Cycle:

1. This cycle assists plants in producing one of their crucial biological molecules, chlorophyll.
2. Through the ammonification process, bacteria and fungi decompose the remains of dead organisms, indirectly contributing to the cleanliness of the environment.
3. It plays a role in providing essential nutrients to the soil by producing nitrite and nitrate.
4. Nitrogen is a vital component of living organisms, and the nitrogen cycle ensures the creation of essential biological molecules within the body of living beings.

12.8 Adaptation of Organisms to Different Environments

In order to survive in their habitat, organisms need to adapt to their surroundings, and this is why we observe organisms thriving in diverse environments. Different environments pose different challenges, such as temperature variations, food scarcity, roaming predators, etc. But even in the face of long-term changes, organisms have evolved characteristics that enable them to survive in those environments. Despite the numerous changes in nature, the major factor behind the stability of the population ratio of species lies in the adaptability of organisms to their environment. The changing patterns of adaptation in specific species within a given environment are evident through different types of morphological and behavioral modifications. As a result, the organism sustains its existence in that environment through successive generations. Below are examples of various environments that provide a clearer understanding of the adaptation process (Figure 12.17).

Desert Region: Various physical adaptations occur in the organisms of the desert region for survival. For instance, they have features to retain water in their bodies, their skin is very thick to reduce water loss from the body, the number of sweat glands is significantly lower, and they have a waxy coating on the body surface that acts as a water-resistant layer. Moreover, the daily behavior of these organisms are also oservaly different. For example, they do not come out in the open during the hottest part of the day. The camel is an example of such an organism. They can store a considerable amount of water in their humps, and their nostrils are structured in a way that prevents water loss during breathing. Not only that, camels can tolerate very high temperatures.

Figure 12.17 : Examples of organisms adapted to specific environments. (a) Camel in the desert region, (b) Dolphin in the sea, (c) Mountain goat

Mangrove Forest: The plants in the mangrove forest, located where freshwater and saltwater meet, possess special adaptations to thrive in both saline water and saline soil. They adapt to the difference of available water level during high tide and low tide, can absorb saltwater through their roots and have specialized respiratory roots in some plants that emerge above the water surface. The Sundari trees in the

Sundarbans create a special respiratory root to survive in the environment of the mangrove forest. Additionally, the photosensitivity of these trees directs them towards sunlight, increasing the amount of photosynthesis.

Marine Environment: The main challenges for marine organisms are salinity, water pressure, and maintaining water balance in the body. Consequently, their bodies are well adapted to swim, and form special respiratory systems to absorb dissolved oxygen from water. Dolphins are an example in this environment. Their bodies are streamlined for swimming, equipped with fins for steering and flippers for speed control. Dolphins also have blowholes for breathing at the water's surface.

Polar Region: The extreme cold temperature, scarcity of food, and the prolonged absence of sunlight in the polar region necessitate adaptations in the resident organisms. Therefore, the animals in this area typically have dense fur, heat-resistant fat layers, and are accustomed to extended periods of hibernation. Polar bears are examples of such animals. They possess thick fur and a dense layer of insulating fat, and the small ears and limbs result in minimal heat loss.

Cave-dwelling Organisms: These organisms inhabit dark environments and have adapted to low visibility by having highly developed senses of touch and smell. Due to the absence of sunlight, their body color tends to be lighter. Blind cavefish is an example. They have lost their sight due to living in the dark but have heightened sensitivity to smell and touch to find food.

Mountain Region: Animals in high-altitude areas need to adapt to low oxygen levels. Their respiratory system is typically larger and more efficient in oxygen supply. Their metabolic rates are slower. An example is the Himalayan Tahr, a mountain goat, which has dense fur for protection against cold and hooves adapted for gripping rocky terrain.

Man-made Environment: Even in man-made environments, animals and birds adapt themselves. In urban areas, creatures often become nocturnals, adapting to life in structures made of concrete or other man-made materials for shelter. Not only that, but these creatures also become accustomed to relying on human-provided food for their sustenance. Rats are a good example for this. They dwell in the caverns and holes of urban structures and survive by consuming human leftovers.

In attempting to adapt to the environment, those organisms that are more successful will thrive, and the inherited characteristics will be noticeable among the descendants. This adaptation to the environment helps protect the existence of the species and ensures the sustainability of ecosystems.

Chapter13

Earth and Universe

Chapter 13

Earth and Universe

The following topics are covered in this chapter :

☑ Age of the earth compared to the universe,
☑ Geologic Time Scale,
☑ Fossils: Definition, Types, Importance,
☑ Earth's changes over time,
☑ Changes in the earth's surface,
☑ Changes in the atmosphere,
☑ Changes in Earth's biota over geologic time

The earth, our planet, is so tiny compared to the vast universe that it's impossible to describe in one word. When we gaze at the night sky, we can't but wonder about our position in the universe. The universe is much older than human generations on earth. In this chapter, we will discuss the age of our earth, its formation process, and the discovery of life. We will mainly try to learn about the natural history of our planet by understanding the origin of the earth, the creation of the earth's crust, oceans, and atmosphere, and the period of the creation of the biota and the process of knowing them.

13.1 Age of the Earth Compared to the Universe:

The universe is still a field beyond the general understanding of humans due to its vastness and age. According to various scientific data, the universe began from an event called the Big Bang about 13.8 billion years ago. Compared to that, the Earth is a relatively new cosmic object, having formed about 4.6 billion years ago. The Earth's mantle and crust formed about 400 crores or 4 billion years ago. Scientists have made a timeline or time frame for determining the age of our planet by examining the decay rate of isotopes (isotope dating) in Earth's rocks and minerals. Although the age of the Earth is less than the age of the universe, the difference in their ages makes the existence of the Earth even more noteworthy. Knowledge of the age of the earth and the universe is necessary to know the secrets of the formation of our planet and to understand the reasons why the earth has become habitable for life.

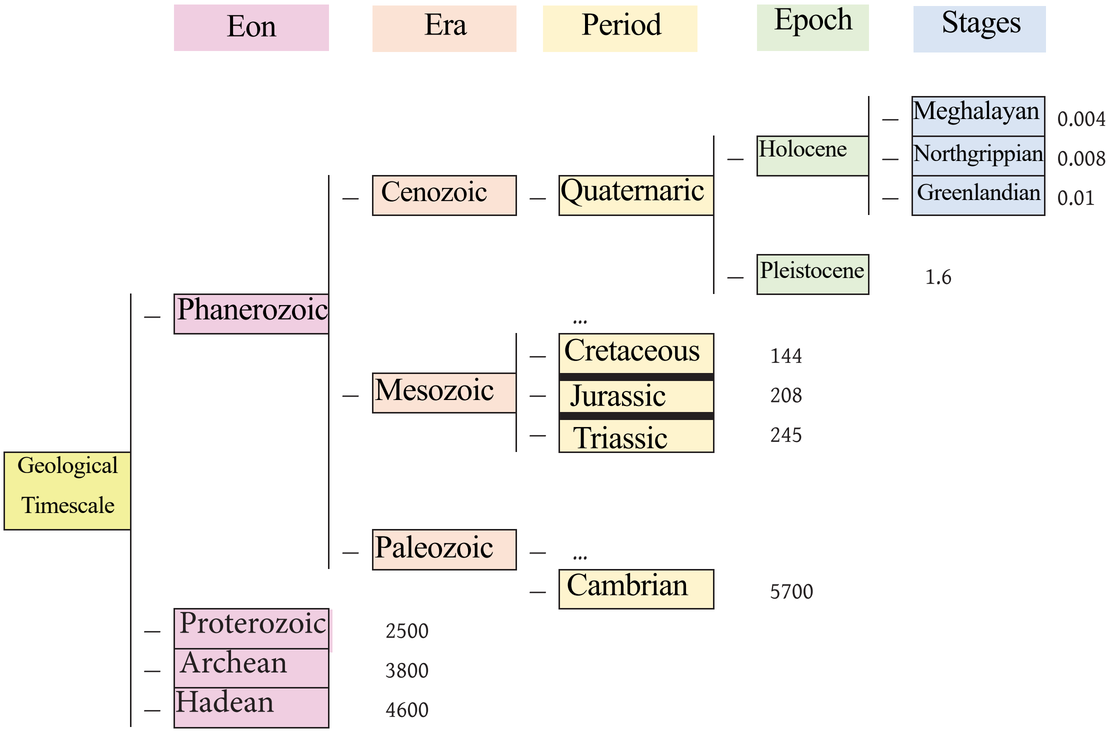


Figure 13.1: Division of geologic time scale. Next to the division is shown how many million years ago this stage began.

13.2 Geologic Time Scale:

Just as the periodic table is an important tool in the study of chemistry, and a map is an important tool in the study of geography, the Geologic Time Scale is an essential tool or method used to describe the history of the earth. It is a system that organizes the history of the Earth into different units of time, both small and large. (Figure 13.1) We use units such as years, months, weeks, days, and hours to measure time. But the history of the earth and the universe is so old that it is very difficult to measure it in months or years, and in many cases, it is not possible. In addition, it is not easy to identify events that occurred long ago. In that case, the history of the earth is described through the geological time scale, based on various significant natural changes.

13.2.1 Units of the Geologic Time Scale

The Geologic Time Scale is divided into the following units. It is important to note that the values of these units are not definite. Depending on important events on the earth, a unit can sometimes be much larger and sometimes smaller. The units are as follows:

Eon: This is the largest unit. In the Geologic Time Scale, there are four eons, namely Hadean, Archean, Proterozoic, and Phanerozoic, in order of antiquity. Each eon is divided into several eras. The other three eons, except for the Phanerozoic eon, are often referred to as Precambrian.

Era: This is the second largest unit of the Geologic Time Scale. For example, the currently ongoing Phanerozoic eon has been divided into three eras. In terms of antiquity, they are Palaeozoic, Mesozoic, and Cenozoic. Each era is again divided into several periods.

Period: The next unit after the era is the period. For example, the Mesozoic era can be divided into three periods, namely Triassic, Jurassic, and Cretaceous, in terms of antiquity. Each period is marked by distinct geological and biological events.

Epoch: The next small unit after the period is the epoch. For example, the most recent period, the Quaternary, can be divided into two sub-epochs, namely Holocene and Pleistocene, in terms of antiquity.

Additionally, for more detailed knowledge, each epoch is divided into several stages or ages. For example, the most recent epoch, the Holocene, is divided into three stages, namely Greenlandian, Northgrippian, and Meghalayan, in terms of antiquity.

Here are some examples of the different units of the Geologic Time Scale. In the time scale chart, the significant units are arranged with their starting time, from which we can find the total period of that unit. It is noticeable that not all periods, epochs, or other units cover the same period. This is because each unit is separated from another by different significant events that have occurred in the history of the earth. These special events include the advent of one or more organisms, changes in the natural environment of the earth, and mass extinctions of various organisms. In the figure, the entire time from the creation of the earth to the present is shown as twelve hours of clock time (Figure 13.2). If we consider 4.6 billion years as twelve hours of the clock, then the advent of humans on earth occurred only two seconds ago!

The Geologic Time Scale is a timeframe that provides a systematic way to study and understand the earth's past. It divides the earth's history into major units based on important geological and biological events. The scale begins with the Precambrian eon, which spans over the vast time from the formation of the earth to the emergence of complex life forms.

The Phanerozoic eon began at the end of the Precambrian era. This eon is marked by the rise of diverse marine life in the Cambrian period at the beginning of the Palaeozoic era, followed by the gradual expansion of plants and animals onto land and the spread of early amphibians and reptiles.

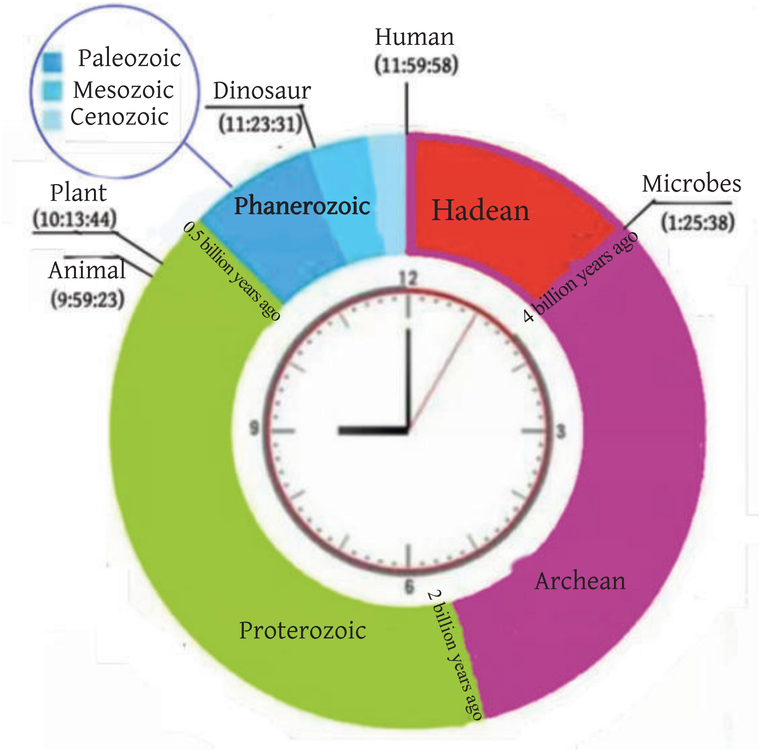


Figure 13.2: Different eons and some notable events have been shown imagining that the earth was created at 12:00 pm and the current time is imagined as 12:00 am. The exact time of the event is shown below the event within these twelve hours.

The Mesozoic era is often referred to as the "Era of Dinosaurs". During this era, along with the dominance of these fascinating animals came the emergence of birds and flowering plants.

Finally, the Cenozoic era, which began about 6.5 crore years ago, continues till the present day. This era is characterized by the rise of mammals, the emergence of humans, and the formation of the modern world.

13.2.2 Formation and Change of Geologic Time Scale:

The Geologic Time Scale is a method for studying the earth's ancient history comprehensively. However, the process of its formation began in the 17th century. At that time, Danish scientist Nicolas Steno proposed a proposition. According to his proposition, the uppermost layer of the layers seen in the rock is relatively new, and the older they will become as you go down successively. In the case of sedimentary rocks, these layers are formed by the accumulation of sediment at different times. This proposition is known as the law of superposition. If we observe, we will see that the different units of the Geologic Time Scale are arranged following the law of superposition. In addition, this time scale can be used to identify events that occurred at different times.

Numerous scientists and geologists have further developed and refined the Geologic Time Scale over the years. For example, in the 18th and 19th centuries, English geologist William Smith and Scottish geologist Charles Lyell, among others, emphasized the importance of fossils in understanding the earth's history. Fossils found in different layers of rock indicate the existence and nature of life at different times in the past. This idea led to the formation of the basic structure of the Geologic Time Scale. Later, when radioactivity was discovered in the early 20th century, it started a revolution in understanding the natural history of the Earth. The radioactive decay of isotopes of elements such as uranium, carbon, and strontium can be used to determine the age of rocks, minerals, and fossils. This has led to the continuous refinement and addition of new information to the Geologic Time Scale. This process is ongoing, and it is likely that new research and technological developments in the future will add even more information to the scale.

By studying the Geologic Time Scale, scientists can reveal a wealth of information about the earth's past. They can use it to identify the evolution of life, detect mass extinctions, understand the shifting of continents, and explore the effects of natural forces such as volcanic eruptions and asteroid impacts. The Geologic Time Scale is an essential tool for understanding the relationships among global events and for interpreting them. It helps paleontologists, geologists, and other scientists decipher the Earth's rich history.

13.2.3 Mass extinctions

Extinction is the complete destruction or loss of all members of a species. For example, all members of a species of dinosaur, Tyrannosaurus rex (T. Rex), have been destroyed. So, this species can be said to be extinct. Similarly, a type of tiger called the Saber-toothed tiger has become extinct and as a result, not a single living Saber-toothed tiger can be found now. Mass extinction is the extinction of thousands of other species such as the Tyrannosaurus rex and the Saber-toothed tiger at the same time. At least five mass extinctions have occurred in earth's history. For example, the Cretaceous-Paleogene mass extinction occurred about 6.6 crore years ago. This event wiped out about 75% of all living species on earth, including the dinosaurs. This mass extinction marks the end of the Mesozoic Era and the beginning of the Cenozoic Era.

However, there are also opposite events. For example, about 54 crore years ago, a large number of new species and complex types of life emerged on earth. This event marks the beginning of the Cambrian period. All of this information about the ancient past is mainly known through the observation of fossils.

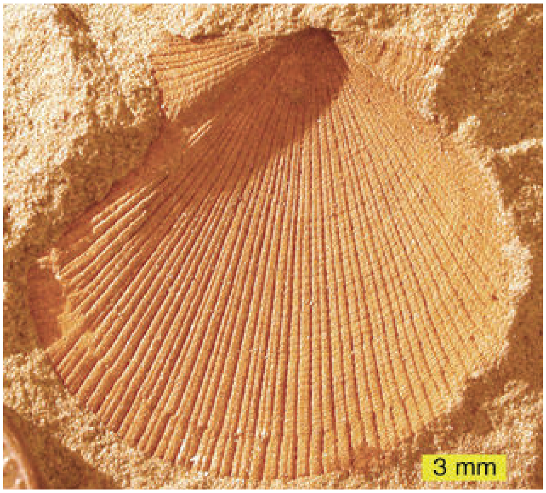
13.3 Fossils:

Fossils are the remains or traces of physical structure or habitation of any organism (plant or animal) that lived in the past. The word fossil is derived from the Latin word "Fossus". Fossils can be of various types, such as bones, teeth, hard outer shells, or even any traces of an organism's body embedded in sediment or rock. Fossils can be of various sizes. From tiny single-celled bacteria to gigantic dinosaurs or parts of plants have been found in the form of fossils. Generally, for an organism to be fossilized, its traces or remains must be at least 10,000 years old. Among the oldest fossils are 350 crore years old single-celled cyanobacteria known as Stromatolites. The types of fossils are as follows:

Fig. 13.3 : A hornet trapped in the glue of a tree that was on Earth -1.5 2.0 million years ago.

13.3.1 Body Fossil:

In this case, the complete or partial remains of an organism are found in the form of fossils. For example, the corpses of early humans frozen in ice or the corpses of woolly mammoths, insects stuck in the glue or sap of trees, etc. Later, the glue of trees accumulates and turns into amber, and the organisms trapped in it often remain intact (Figure 13.3).



1Fig. 13.4: Molds and cast fossils of an oyster type animal from about 6 crore years ago.

13.3.2 Mold and Cast Fossils:

In many cases, the remains of an organism buried in the sediment turn into sedimentary rocks over time. Later, the organism's remains decayed, but its imprint remained on the rock. These are called molds. When the mold, or hollow space within the mold, is refilled with sediment and hardens to resemble the body of the organism, it turns into cast fossils (Fig. 13.4).

Figure 13.5: Footprints of dinosaurs living during the early Jurassic period

13.3.3 Trace Fossils:

Sometimes traces of life or movement of organisms are found in sedimentary rocks or sediments. For example, footprints, paths created by movement, living burrows, built nests, etc. (Figure 13.5).

13.3.4 Permineralized Fossil:

In many cases, the tiny voids or pores within the solid body of a dead organism become filled with minerals (usually waterborne) and preserve the body's shape and size. Sometimes the mineral replaces the material of the organism's tissue. An example of such a fossil is a petrified wood (Fig. 13.6).

Fig. 13.6: Petrified wood

Fossils open up the window into the past to us. By observing fossils, we can learn about the structure of the organism and the environment at that time. For example, if fossils of marine organisms are found in the soil or rocks somewhere away from the sea, then it can be easily assumed that there was once a sea or an ocean. For example, fossils of various types of aquatic animals are found in the sedimentary rocks found in the Tekerghat area of the Sylhet region of Bangladesh. So, we know this area was once under the sea. Nowadays it is possible to determine the actual time of the organism's location on Earth through modern radioisotope dating.

13.4 Earth's changes over time:

Radioisotope dating of rocks and other methods suggest that the earth formed about 460 crore years ago. The first two changes that took place on earth during this period were (1) changes in the earth's surface and (2) the origin and modification of the earth's atmosphere. A third change that naturally results from these two changes is, (3) a change in the earth's biota. These three changes are briefly described below.

13.4.1 Changes in earth's surface over geologic time

460 The period from 460 crore years ago to 57 crore years ago is called Precambrian. About 85% of the Geologic Time Scale belongs to this period. The pre-Cambrian period is divided into Hadean, Archean, and Protozoic eons.

The Hadean is the oldest and shortest period of the three eons of the Precambrian period (460 crore years ago to 400 crore years ago). At that time, the earth's formation process was going on. Earth's natural conditions were completely hostile to life. Due to the earth's gravity, numerous asteroids, comets, and other small and large cosmic objects were crashing on the earth's surface. Earth's atmosphere consisted mainly of hydrogen and helium gases. There was almost no oxygen. The primordial oceans also began to form at the end of this eon. The first minerals and rocks in the crust were also formed during this time.

Then came the Archean (400 crore years ago to 250 crore years ago) and the Proterozoic (250 crore years ago to 54 crore years ago) eons. During the Archaean eon, the first continent formed, and earth's environment became congenial to life. The first sedimentary rocks were also formed during this time. The first signs of plate tectonics were found in the Proterozoic eon. During this time, the first supercontinent and the first ocean crust were formed.

13.4.2 Changes in earth's atmosphere over geologic time

Through a process called degassing, various gases including water vapor, sulfur, and nitrogen oxides were released from the earth's lithosphere, and the original atmosphere was formed. Later, with the arrival of photosynthetic cyanobacteria, the atmosphere got the oxygen supply which increased with the vegetation growth. After the ozone layer was formed, it absorbed the sun's harmful ultraviolet rays and started protecting the earth's surface from its effects. As the surface of the earth became more suitable and safer for life, the number of species also increased. It should be noted that as a result of the ozone layer, apart from the sea, various species of life begin to emerge and flourish on land. The source of the earth's water is mainly identified with comets that hit the earth in its early stages. However, by examining the rocks obtained from deep in the earth's surface, it has been found that water is associated with molten rock under special conditions at high temperatures and pressure in the earth's mantle, which is much more than the water found on the surface.

13.4.3 Changes in earth's biota through geologic time

Life on earth has undergone tremendous changes throughout its history. From the earliest single-celled organisms to the complex ecosystems we observe today are continuous changes in life forms to adapt to the environment (Figure 13.7). This process of change is known as evolution. Through processes such as natural selection, genetic variation and adaptation, species have evolved diversely and sometimes become extinct. The fossil record serves as an important tool for tracing the evolutionary journey of life on earth.

Over millions of years, the biota has undergone significant changes and adaptations. For example, the transition from aquatic to terrestrial habitats resulted in the fulfilling of land

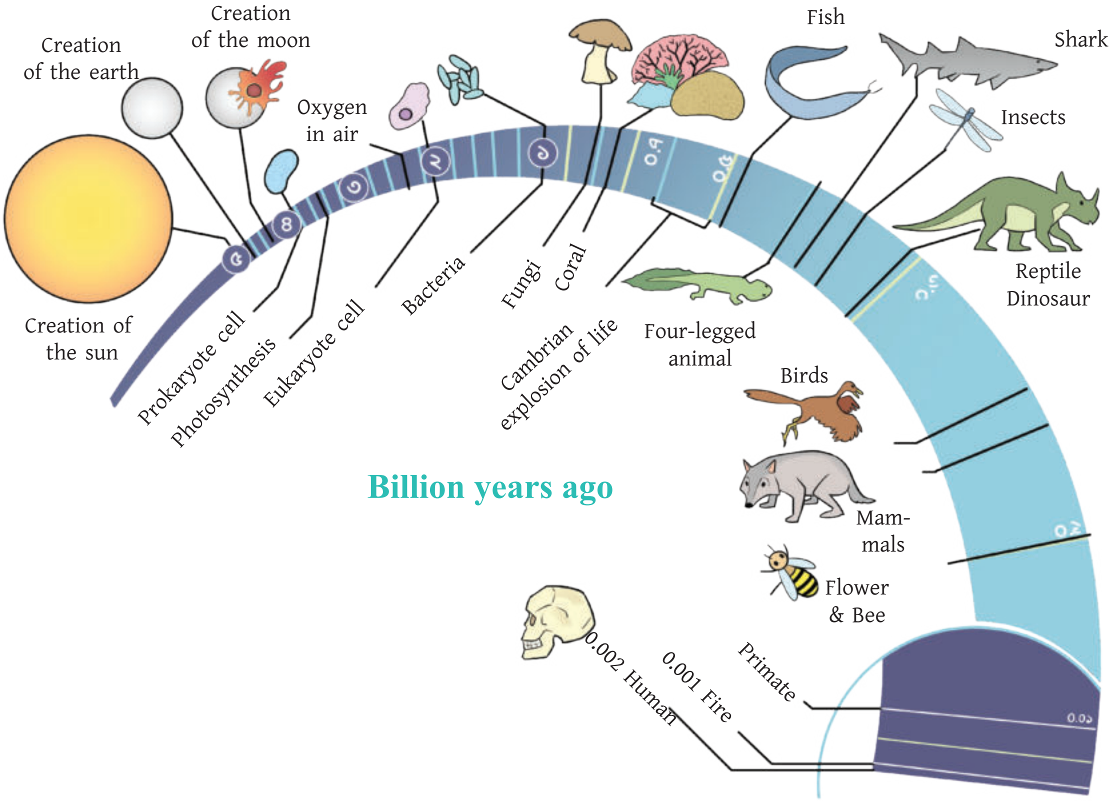


Figure 13.7: Origin and development of life on Earth

by plants and animals. This transformation marked a pivotal moment in earth's history and laid the foundation for the extraordinary diversity of life we see today.

Another significant change was the rise and dominance of reptiles during the Mesozoic Era, commonly referred to as the "Era of the Dinosaurs". Dinosaurs and other ancient reptiles then dominated the land. Their evolution was intricately linked to changing environmental conditions and new environmental changes.

After the abrupt extinction of the dinosaurs, the Cenozoic era saw the arrival of mammals, and their subsequent diversification ushered in a new era of life on earth. Mammals adapted to different habitats, developed complex social behaviours, and eventually gave rise to primates, including humans.

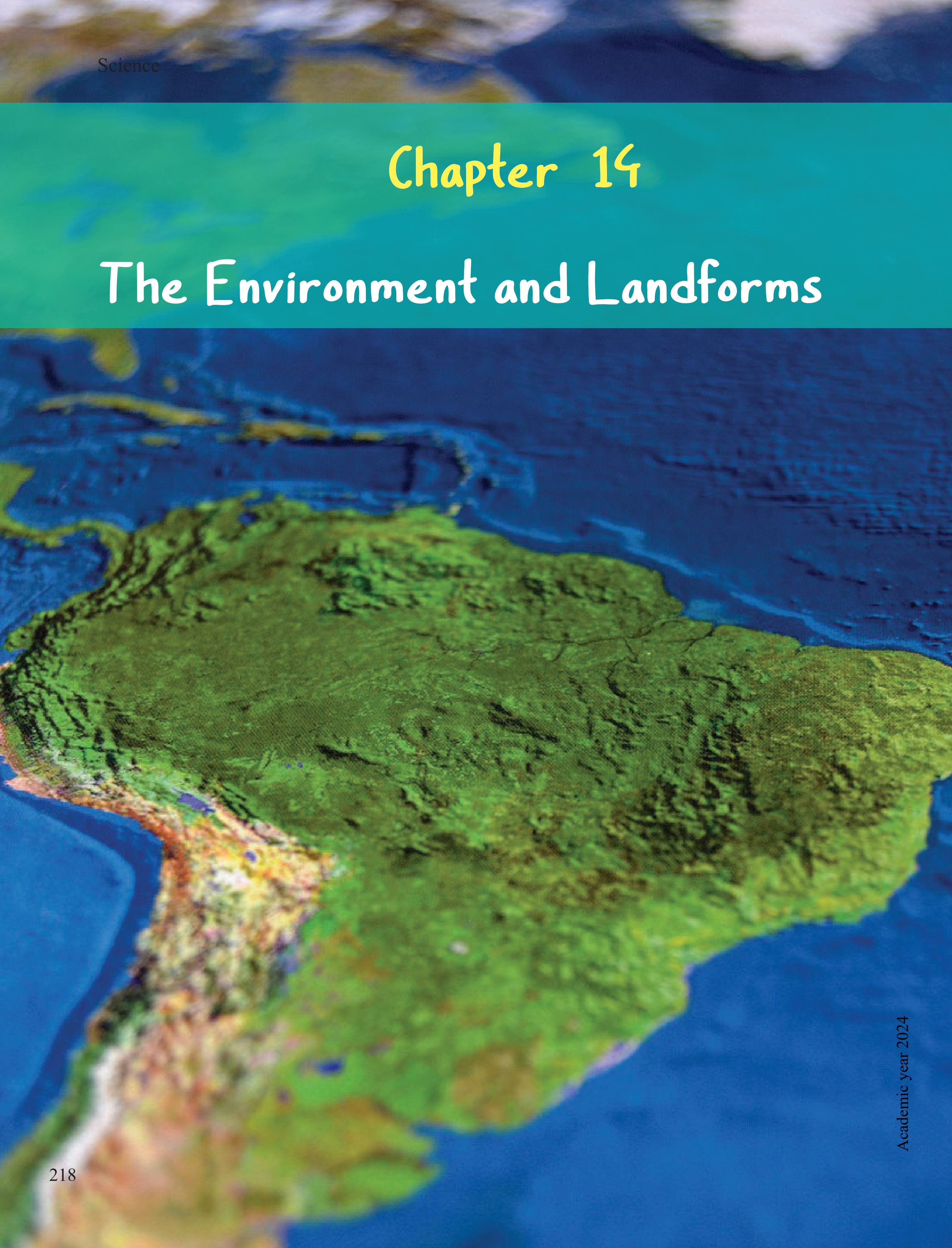
The study of life’s changes over time provides insights into organisms and their interactions with their environment. It highlights the role of environmental interactions and genetic variation in determining the course of evolution. By examining the patterns and processes of change in organisms, scientists gain a deeper understanding of our place in the complex web of life.

By studying earth's history and the changes that have occurred over time, we can sense our place in the universe. We can think about the sensitivity of our planet and the responsibility humans have as superintendents of its future.

Let us never forget that earth is so far the only habitat for life that makes the earth unique from other planets.

Chapter 14

The Environment and Landforms



Chapter 14 The Environment and Landforms

The following topics are covered in this chapter :

☑ The origin and types of ground water
☑ Formation of various types of landforms
☑ Various processes involved in the formation of landforms
☑ Endogenic process
☑ Exogenic process
☑ Formation of various types of landforms and nature of biodiversity
☑ The mountains
☑ The hills and hillocks
☑ The plateau
☑ The plain

Less than one thirds of the earth surface consists of land, the landform of this land is full of variety. The variety in the landform is caused by the diverse climate across the globe and different types of energy sources found beneath the ground. On the one hand, a special kind of landform is seen along the plate's edge due to the dynamic nature of the tectonic plate while the landforms in the equator or polar region have unique features due to the climate. More than 70% of the earth surface is water; not only that, water exists even on the land either on or beneath its surface. This water plays direct or indirect roles in the formation of the climate and landforms in different parts of the world. The natural formation and the environment of a certain place affect the process of land formation, on the other hand, the environment of that place is also affected by various types of landforms.

14.1 Ground Water

You must have seen the water in the rivers-streams, canals-swamps, ponds and pools around your residence. Not only that, you must have seen torrential rain in the rainy season and might have the notion that the water found on the land areas of the earth surface could constitute a large portion of earth water. In fact, this is not true at all.

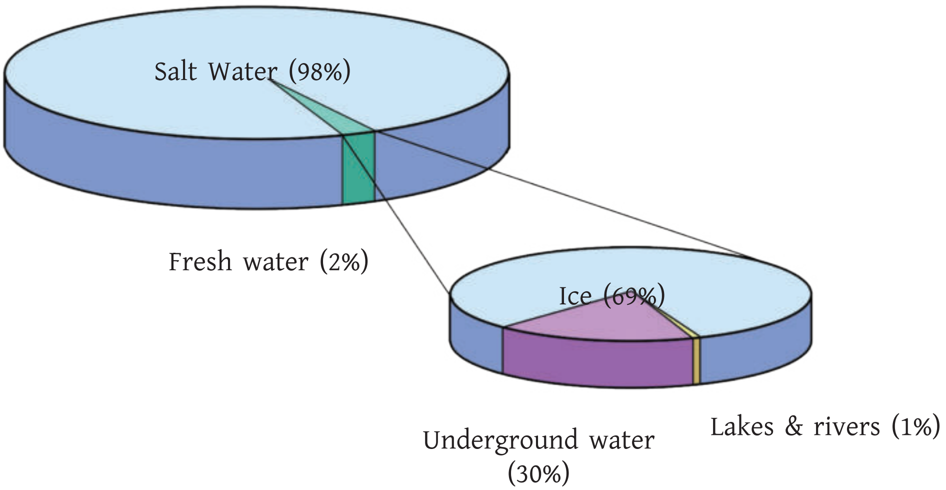


Figure 14.1: Various types of water on earth and their amount

This water on the land surface constitutes only a tiny portion of the total water on earth (Figure 14.1). 98% of earth water is the saline water found in the seas and oceans, only 2% is fresh water. If we consider this 2% fresh water as 100 percent, 69% of it is available in the Polar Regions or High Mountain picks as ice or Glacier. Another 30% of the rest 31% is ground water, which is available under the earth soil. The rest 1% water is the water from the rivers, canals and bils or from the rains and clouds.

We see raining at various times of the year, especially during the monsoon. When there is a rainfall on the land surface, a number of actions take place during and after that. For example-

[1] The rainwater reaches the soil being drained through or spilt off the branches and leaves of plants. This might be called through flow of the plants. If there are no shades of trees, the rainwater hits the earth surface.

[2] A large portion of rainwater flows over the earth surface, reaches the rivers and then flows further to fall into the sea. This is called surface runoff.

[3] A small amount of water enters into the ground. This is called infiltration. In this method water gets swollen in the tiny pockets within the soil which can be consumed by plants as per their needs.

The rest of the water pours further down the earth through the gaps of gravels or through the cracks of rocks and is collected as ground water. In this case the cracks inside the soil or rocks and the tiny empty pockets are totally filled with water. If the water arrives at any impermeable rock when it infiltrates into the ground, it can no go down deeper. Instead, it starts to get

Deposited in the tiny pores or fractures on the rocks or the sediments of that rock. This results in the formation of a water reservoir under the ground, which is called Aquifer. Since there are huge openings within the loose rocks, water can infiltrate and be deposited in them. Therefore, the loose layers that is made up of sands, sand stones and lime stones

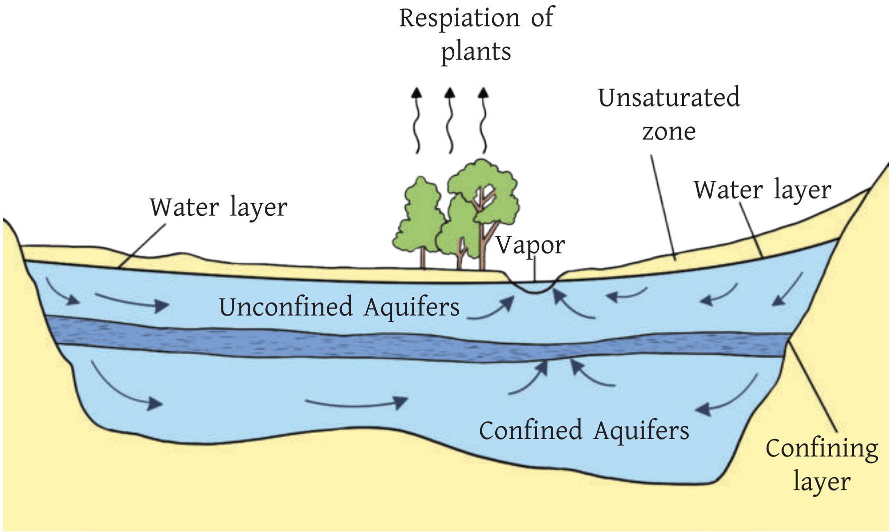


Figure 14.2: Position of two types of Aquifer. It is worth noticing that it may take several lakh years to have the ground water deposited.

acts as a good aquifer.

Based on the position of permeable and impermeable rocks aquifers can be of two types; For example-

[1] Unconfined Aquifers

[2] Confined Aquifers

14.1.1 Unconfined Aquifer:

If there are impermeable rock layers between a ground water layer and the earth surface, the water on the earth surface can infiltrate into it. For this reason, if the water from this layer is pumped out, it is possible to get this filled with water again. On the other hand if an impermeable layer is formed on the earth surface due to the presence of concrete layers, roads, buildings or other constructions, the refilling of the aquifer water is interrupted. In such case, the ground water table in that place might be going downward due to too much extracting of water. In many places of Bangladesh the ground water tables have gone lower compared to their previous levels. In that case, in order to extract water in those areas the pipe of tube well or pump need to be fixed at a much deeper level under the ground.

14.1.2 Confined Aquifer:

The confined aquifer is situated much deep inside the ground compared to unconfined aquifer. There are to impermeable rock layers above and below this aquifer. Water can hardly infiltrate through this confined layer. If there are some pores or fractures in that impermeable aquifer, water will come out from these pores or fractures even though no external force is applied. This happens so because of the high water pressure that is caused by the weight of the upper layers of rocks and the water that flows from the unconfined area. When the high-pressure water beneath the ground comes out through the pores and cracks of an confined aquifer it is called Artesian Well.

14.2 Formation of various types of landform

Various types of landforms are seen at various parts of the world. In Bangladesh we see alluvial plains extended over a vast area. There are hills and hillocks in the North and South-Eastern regions of this country. There are low marshy lands spread over a large area of Sylhet division. If we go beyond Bangladesh and look at other parts of the world, we will see a variety of landforms such as deserts, glaciers, high mountains, valleys, deep tracks under the ocean, lakes, volcanoes etc. These landforms are created due to various natural factors. Even human activities may cause reformation of a particular type of landform to another type.

I this chapter we will learn about the natural process of land formation. In case of formation of earth's landform some forces act from inside the ground and some forces act out of the earth surface. Hence, the natural causes of landforms can be divided in to two types. For example-

[1] Endogenic Process

[2] Exogenic Process

14.3 Endogenic Process

In such processes, the force and process of restructuring of landform act out from inside the earth. We learnt about Plate Tectonic in the previous classes. Basically endogenic processes are related with plate tectonic. Two kinds of things might occur in this instance, there might be a change in the size and position of the rocks residing in the highest level e.g. earth surface or there

might be an eruption of magma from inside the earth giving birth to volcanoes. For this reason, the endogenic processes can be divided in to two types,

[1] Diastrophism

[2] Volcanism

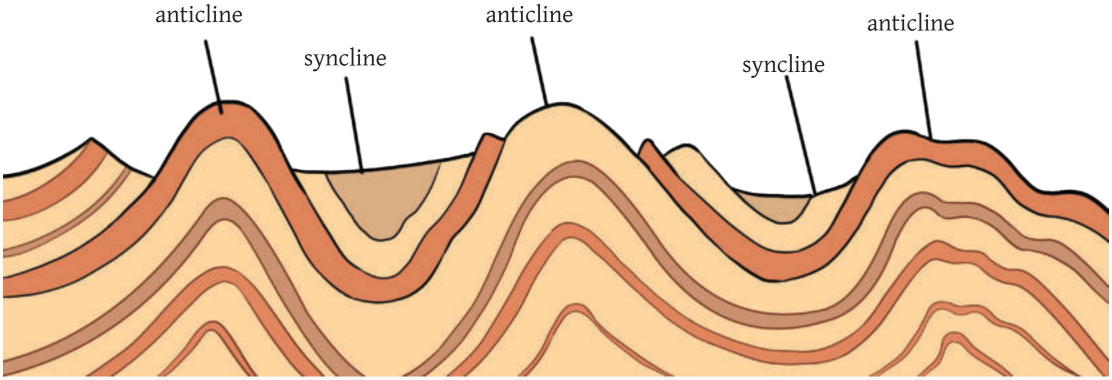


Figure 14.3: The elevated or arc-like parts in the fold are Anticline and the low basin like parts are called Syncline folds

14.3.1 Diastrophism

If force is applied to the rock on earth surface, there will be changes in the shape and size of the rock. This change depends on the degree and direction of the force that is applied to the rock. Two types of forces are in action in these instances. For example-

a) Compression force

b) Extension force

In the instances of compression or extension forces, the rock gets compressed owing to the force applied on the rock from two directions.

Folding: We learnt in the past that different types of rocks have difference level of solidity. As a result the capacity to cope with the force applied on the rock also varies. If compression force acts on the rock on the earth surface from opposite directions, that rock gets distorted and it has folding in it. In this instance, the rock only changes its shape, but does not get smashed. Thearched part of the folding is called Anticline while the concave dipped part of the folding is called Syncline (Figure 14.3).

Mountains are created from Anticlines while Valleys originate from Synclines. If we place this Science book on the table and

Figure 14.4: Folding in the lime and chart stoe layers in Greece. These were parallel to the earth before. Later, such folds were created due to compression force.

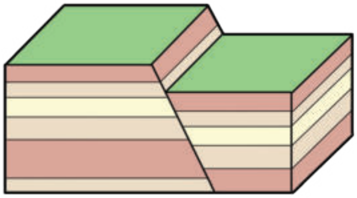
Figure 14.5: One piece of rock may changes position with another rock just along that fracture line like this one seen in Morocco

apply force on it from two sides, we will see that the middle part of the book has a fold which has gone upward. Like the many book leafs get folded in this instance, many rock levels on the earth surface also gets folded (Figure 14.4)

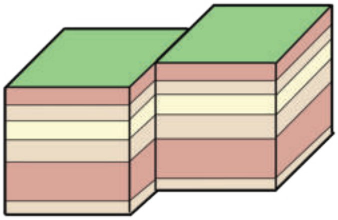
Besides mountains and valleys another type of landform is the plateau. A Plateau is an extended plain or partly curvy land situated at a much higher place. The surrounding of a plateau has sharp slopes which looks like a table. Among some significant plateaus in the world are Pamir and the Plateau of Iran. A plateau can be formed by being decayed by water and glaciers, volcanic eruptions, plate tectonic etc.

Faulting: If a fracture is caused by application of compression or extension forces on a rock in a certain part of the earth surface, one piece of rock may changes position with another rock just along that fracture line (Figure 14.5). The rock gets fractured as it cannot bear with the force applied to it. In this case, a piece of rock may either (1) go downward from the other or (2) change its position horizontally, or (3) go upward. Considering these, there are three kinds of faultings, for example-

Normal fault



Strike fault



Reverse fault

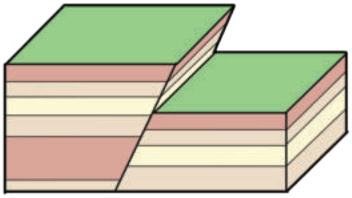


Figure 14.6: Normal, Strike and reverse faults

(a) **Normal slip faults:** In case of mormal faults a piece of rock goes below another rcok. It is worth noticng that, in such cases the the rock part that stays at the top makes an obtuse angel with the rock that goes down. The vsisible part of the upoward rcok piece is called a folding or 'Kharai'.

(b) **Strike slip faults:** In case of such faulting two pieces of rock exchanges positions mutually. No fault is visible in this instance as there is no faulting toward the raised end.

(c) **Reverse slip faults:** In such faulting one rock goes over another rock and some portion of the upward rock piece keeps hanging over the rock piece below. In this case the upward rock makes an acute angel with the rock residing below. When this angel is very small (smaller than 10 degrees) it is called over thrust faulting.

14.3.2 About Volcanism

An example of a nice landform caused by endogenic processes is volcano (Figure 14.7). In this case, melted rocks, ashes, various gases, vapors, heated stone pieces comes out of the ground. The melted rock staying inside the ground is called magma and when it comes out of the ground, it is called lava (Figure 14.8). Volcanoes may vary based on various factors. Based on the types of lava volcanoes can be of two types- for example

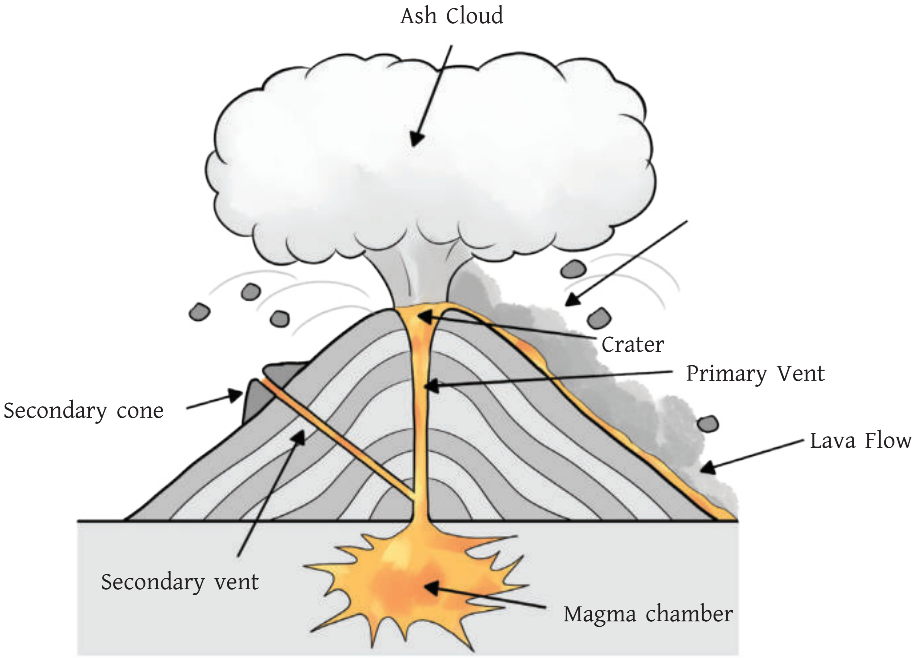


Figure 14.8: Various parts of a volcano

Figure 14.7: Positions of volcanoes that has erupted in last 12000 years. Here each dots represents one or more volcanoes.

Explosive volcanoes: The type of a volcano depends on factors like the characteristic of lava, amount of gases in it etc. The characteristic of lava is mainly determined by the amount of

melted silica (SiO2) in it. If the proportion of silica is high in lava it is called acidic lava. As this type of lava is thick, it cannot come out or flow easily. The volcanoes that erupt this types of lava are explosive in nature. For example the Mount St. Helen situated in California in the USA.

Quiet or Shield volcano: The lava which has lower amount of silica is knows as basic type of lava and this type of lava can flow with ease. Such volcanoes can erupt lava without any explosion. Usually when two tectonic plates are going apart from one another, new plates are form in that place following such process. Since this lava can flow easily, the slop of the volcano consists of such lava is smooth and spread over a large distance. As these volcanoes look like the shields used in the battle fields, they are called Shield Volcanoes. The Shield Volcanoes of Hawaii Islands are examples of such volcanoes.

Again, based on the active status of the volcanoes they can be divided into three types.

(1) Active Volcano: The volcanoes in which volcanic eruption is taking place at present.

(2) Sleeping Volcanoes: This type of volcanoes had eruption in the past but it has been stopped since many years. If the Magma Cells are filled again with magma, there is a possibility of volcanic eruption in future.

Figure 14.9: The Sabancaya volcanic eruption in Peru in 2017

Dead Volcanoes: This type of volcanoes had eruptions in the past but there is no more any possibility of volcanic eruption now or in future.

Figure 14.10: the Tonga Island in the Paciifc Ocean. Made from oceanic volcano

The types of volcanoes may also vary on the basis of their structure or physical appearance. Besides, there is one type of volcano known as Super Volcano. In such type of volcano eruptions take place once in a thousand years. The amount of lava and other substance erupted through this volcano is higher than the other volcanoes. The volcanoes in Mount Toba in Indonesia and the

One at the Wellstone National Park in the USA are examples of such volcanoes. If super volcano wakes up and if there is a volcanic eruption from it, it may affect the whole world.

So far we have learnt about the volcanoes found on the surface of the earth. However, there are such shapes created inside the ground because of volcanic eruptions which can be only visible when the soil surface is decayed.

Oceanic volcanoes:

Volcanoes are found under the sea as on land and they also erupt from them. The lava that comes out of this type of volcano comes in contact with sea water and forms mountains under the water. When the height of these mountains rises and comes out of the sea level, they form islands in the seas and oceans. Tonga, an island in the South Pacific, is considered to be the newest island to develop in this way (figure 14.10).

14.4 Exogenic Processes

Such a process in the formation of landforms is carried out by objects and energies outside the surface. The substances by which this process takes place are called agents. Water, air and ice are the three agents that work in the exogenic process. There are three basic steps in the exogenic process; Such as-

1. Erosion work,
2. Transportation
3. Sedimentation

At each of these stages, different types of landforms are created. However, the formation of such landforms by the agent in these three steps and their places are determined by the location and

climate of that place. For example, in places where there is an abundance of water and there is a lot of rainfall, water acts as a landform agent. There is a lack of water in dry places. In that case, the air plays the role of an agent. Again, ice acts as an agent in very cold regions.

14.4.1 Erosion

The process of weakening and eroding of rocks by natural forces is called weathering. First, surface rocks are crushed by various processes and removed by agents. There can be deflection in three processes. Such as-

1. Physical weathering
2. Chemical weathering
3. Organic deformation

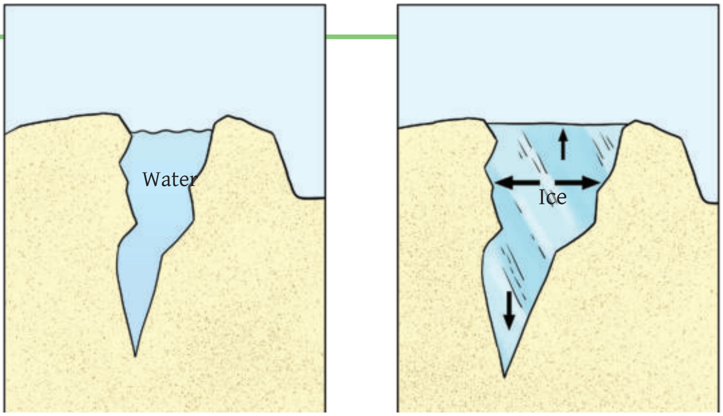


Figure 14.11: Frost action

Physical weathering

In this process, rocks are affected by various physical forces and are fragmented into relatively smaller particles. In this case, the chemical composition of the minerals that make up the rock remains intact, only the size and shape of the rock changes. For example, a large granite (a type of igneous rock) stone is reduced to relatively small pebbles by physical erosion. Some of the different types of physical deflection processes are as follows:

Frost action

In cold regions, liquid water enters the cracks between rocks during the day and freezes into solid ice during the night. When the water turns into ice, it increases in volume and puts pressure on the cracks. As a result, the cracks are widened. During the day, the heat of the sun melts the ice back into water, and the larger cracks formed at night can allow more water to enter (Fig. 14.11). Later, when it turns into ice again at night, it creates more pressure on the stone and increases the cracks. Thus the hard rock breaks down into smaller pebbles (Fig. 14.12).

Salt crystal growth:

This process is similar to the process of freezing, but in this case, salt crystals apply pressure on the cracks in

Figure 14.12: The crack in the rock created by frost action

. Figure 14.13: Landform created through salt crystal growth in Salt Point State Park, California

Figure 14.14: Landform created through exfoliation process in Yosemite National Park, California

the rock. Water evaporates rapidly in many arid regions of the world. As a result, the dissolved salt in that water becomes crystal. As the salt crystals grow, the cracks between rocks create more pressure and physical deformation occurs (Fig. 14.13).

Thermal action: In some places, there is a big difference between the temperature of day and night. In those places, the rocks expand during the day by the heat of the sun and contract by the cold at night. We know that rocks are a mixture of different types of minerals. Figure 14.13: Landform created through salt crystal growth in Salt Point State Park, California

Different types of minerals expand at different rates due to heat. As a result, due to pressure differences in different parts of the rock, it starts to break down.

Exfoliation: The rocks that are deep under the ground are somewhat compressed by the upper soil and the pressure of the rock. When the upper rock or soil is removed with the change of time, the lower rock is exposed to the surface. Due to the lack of the pressure applied on these rocks, they expand and many parallel cracks are formed. Thus, the rock breaks down in layers like onion peels (Fig. 14.14).

Chemical weathering: When rocks are crushed by chemical processes, it causes chemical deformation. In this case, rocks vary not only in size, but also in chemical composition. Chemical decomposition can vary with chemical reactions such as-

Fig. 14.15: A marble stone sculpture eroded due to acid rain

Oxidization: Oxygen dissolved in air and water reacts with minerals in the rock to form new substances. Generally, metallic minerals are converted into oxides and hydroxides in this process. In this case, the new substance is structurally weaker than the previous mineral and breaks down easily. Sometimes the newly created material increases in volume and helps to break the rock by creating pressure.

Hydration: Rock-forming minerals can react with water to form new compounds. An example is the mineral feldspar which is located in granite rock (which is a very hard rock). When it reacts with water, it turns into relatively soft clay or mud and silica sand.

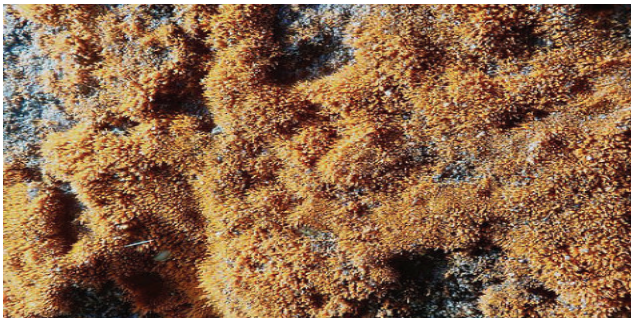


Figure 14.17: Rock erosion caused by small microorganisms in Spain (La Palma)

Hydrolysis: In this case, water molecules combine with mineral compounds to form heterogeneous minerals. For example, water joins with a mineral called anhydrite to form gypsum.

Acid reactions: The Carbon dioxide in the air combines with rainwater to become weak carbonic acid. This acid reacts with carbonate-like rocks to produce carbon dioxide gas and erodes the rock. Rocks such as limestone, marble, etc. are chemically eroded by reacting with various acids. Many of us have seen marble

sculptures or foundation stones eroding mainly due to acidic reactions (Fig. 14.15).

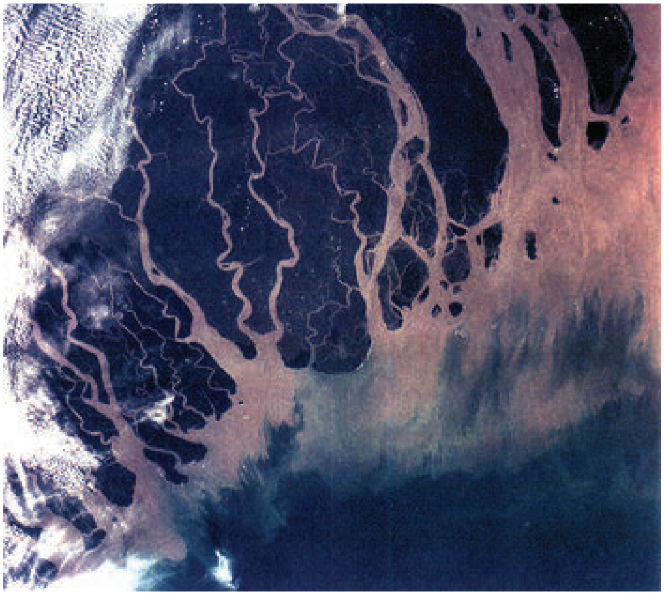


Figure 14.17: the Ganges Delta in Bangladesh and India

Biological weathering: In many cases, rocks can be crushed by plant and animal activities. For example, some plants can grow on stones. The roots of these plants penetrate deeper by putting pressure on the rock, causing cracks in the rocks.

Over time, the stone gets eroded into smaller pieces. Many of us have seen banyan or pakur trees growing on different buildings. Due to the roots of these trees, cracks are created in the walls or roof of the building. Rock erosion can also be caused by small microorganisms. In this case, the chemicals released from those microorganisms help the erosion process of the rock (Fig. 14.16).

14.4.2 Transportation

The sediment is transported by water, air or ice after fermentation. In this case, the speed of that transportation process depends on what is being transported by the sediment. For example, the transport of water in the river takes place relatively quickly. On the other hand, the transportation process by ice or glaciers is relatively slow (two to three feet a day). The speed of sedimentation transport may vary with the change in wind speed. The amount of sedimentation to be transported depends on the transport agents. For example, in mountain rivers, many large pieces of stone are transported. Large rocks can also be transported in glaciers. On the other hand, as the density of air is about 1,000 parts of that of the water, it cannot transport large sediments. In that case, sand or dust is transported through the air. In many cases, the distance of this transport can range from a few hundred meters to several thousand kilometers. It may seem unbelievable to you that fine silt dust is transported from the deserts of Africa via the Atlantic Ocean to be finally deposited in South America.

14.4.3 Deposition:

Sediments transported by water, wind, and ice eventually accumulate in different places to form different types of landforms. For example, river-borne sediments form floodplains. Deltas are formed where river water meets the sea (Fig. 14.17). Airborne dust accumulates to form fertile land called loesses. Desert dunes of various sizes are also formed by accumulation of

Figure 14.18 Moraines collected around the Icy Lake in Bulgaria

airborne sand and change position with wind over time. Sediments transported by glaciers are deposited in different types of moraine

14.5 Nature of biodiversity in various landforms

The biodiversity of a place is based on the structure and type of landform. We see many types of landforms like mountains, plateaus, plains, deserts, etc. all over the world. Different landforms have different climates and environments that affect the biodiversity of the place. For example, in the desert, the climate is very dry and water is scarce. The days are very warm and the nights are extremely cold. So the animals and plants that live there are of unique characteristics. The desert cactus can store a lot of water in its trunk. On the other hand, desert camels, small rats, small insects, snakes, etc. can survive by taking little water.

High mountains or mountains are usually very inaccessible. So the animals living there are also adapted to

that place. For example, goats living in the mountains can move along very high and dangerous steep slopes. The tallest mountains and the colder places of the world are covered with snow. So many trees grown there are angular. This can easily cause the snow to fall on the tree. At the same time, animals in those places are more cold-tolerant and usually have a thick layer of fat under their skin and long fur on the outside. This protects them from the cold. Snow leopards, Andean condors, long-horned sheep, ibex, mountain gorillas, lynx, etc. are among the animals that live in cold and mountainous places of the world.

Although the plains are in different parts of the world, there are different types of climate. In this case, the climate of that place is largely dependent on the latitude. Therefore, different types of biodiversity can be seen in the plains of different places.

নিরাপদ সড়ক: দায়িত্ব আমারও

আমি পথচারী, চালক অথবা শৃঙ্খলা রক্ষাকারী যখন যে অবস্থানে থাকি না কেন, নিরাপদ সড়কের দায়িত্ব আমারও। আইন মান্য করা, সচেতনতা আর দায়িত্বশীলতাই পারে নিরাপদ সড়ক উপহার দিতে।

পথচারীর দায়িত্ব: রাস্তা চলাচল ও পারাপারে ফুটপাথ, জেব্রা ক্রসিং ও ফুটওভার ব্রিজ ব্যবহার করা। ফুটপাথ না থাকলে রাস্তার পাশ দিয়ে চলা, পাশাপাশি কয়েকজন না হেঁটে লাইন ধরে ঝুঁকিমুক্তভাবে হাঁটা, রাস্তা পারাপারের নিয়ম মেনে চলা।

চালকের দায়িত্ব: নিয়মানুসারে নিয়ন্ত্রিত গতিতে গাড়ি চালানো, বৈধ লাইসেন্সসহ গাড়ি চালানো, নিবন্ধিত গাড়ি চালানো, সড়ক আইন ও ট্রাফিক সংকেত মেনে গাড়ি চালানো।

Academic Year 2024

Class Nine Science | Investigative Study

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