

Nothing tends so much to the advancement of knowledge as the application of a new instrument. The native intellectual powers of men in different times are not so much the causes of the different success of their labours, as the peculiar nature of the means and artificial resources in their possession.  
 . . . . . Sir Humphrey Davy,



State Council of Educational Research and Training  
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PHYSICAL SCIENCES

CLASS 10



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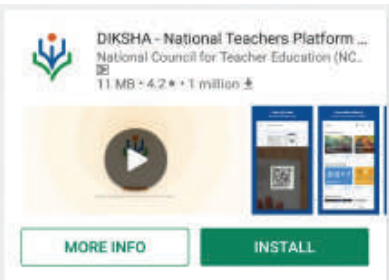



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- Identifying intelligent students and encourage them to study science from early age
- Develop complex human resources to promote scientific, technological development and research

Inspire is a competitive examination. It is an innovative programme to make younger generation learn science interestingly. In 11<sup>th</sup> five year plan nearly Ten Lakhs of students were selected during 12<sup>th</sup> five year plan (2012-17) Twenty Lakhs of students will be selected under this programme.

Two students from each high school (One student from 6 - 8 classes and one from 9 - 10 classes) and one student from each upper primary school are selected for this award.


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# PHYSICAL SCIENCES

## CLASS X

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# Intro ...

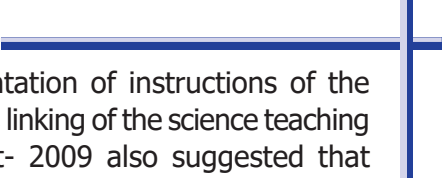
We believe that class-10 education is a key aspect of school education and a turning point in student's life. The present tenth class Science textbook in your hands is developed in accordance with the National and State Curriculum Framework and the Right to Education Act. This book helps the student to review various concepts that were learned through the learning experiences provided in the school and to get comprehensive knowledge about these concepts. The lessons in the textbooks are presented in such way that they help in preparing the student for competitive examinations and also to prepare him/her for intermediate education.

The new science textbooks are specially designed with suitable pedagogy in tune with Continuous Comprehensive Evaluation (CCE) which we are right now implementing in school education. These textbooks help the teacher to assess students learning during teaching learning processes. They facilitate effective learning of various concepts of science in scientific method apart from getting knowledge about concepts. It is essential to complete the syllabus in the stipulated time as students have to write the Board Examination in class-10. But don't forget that completion of syllabus means making the students understand the concepts and trying to achieve the learning competencies. It is mandatory on the part of teacher to implement teaching strategies like, making the student to read the content of the textbook, do discussion, analysis, lab activity, field trips, preparing reports, etc. Teacher must take special care to avoid the practice of rote memorisation of scientific information from guides and question banks.

The classroom teaching of science must be in such a way that it encourages children to think and work scientifically. Also, it must enhance love towards nature. Even it should enable to comprehend and appreciate the laws governing the nature in constructing so much diversity all around. Scientific learning is not just disclosing new things. It is also necessary to step forward without interrupting the interrelationship and interdependency along with understanding of the nature's intrinsic principles. High School children possess cognitive capacity of comprehending the nature and characteristics of the transforming world surrounding them. And they are able to analyze abstract concepts.

At this level, we cannot quench their sharp thinking capability with the dry teaching of mere equations and theoretic principles. For that, we should create a learning environment in the classroom which provides an opportunity for them to apply the scientific knowledge, explore multiple alternatives in solving problems and establish new relations.

Scientific learning is not just confined to the four walls of classroom. It has a definite connection to lab and field as well. Therefore, there is a lot of importance to field experience/ experiments in science teaching.



There is a great need for compulsory implementation of instructions of the National Curriculum Framework- 2005 which emphasizes linking of the science teaching with local environment. The Right to Education Act- 2009 also suggested that priority should be given to the achievement of learning competencies among children. Likewise, science teaching should be in such a way that it would help cultivate a new generation with scientific thinking.

The key aspect of science teaching is to make the children understand the thinking process of scientists and their efforts behind each discovery. The State Curriculum Framework- 2011 stated that children should be able to express their own ideas and opinions on various aspects. These Science Text Books are prepared to meet the standards set by the SCF and thus assist children in becoming self-reliant researchers capable of thinking intensely in scientific terms.

The new textbooks are developed to achieve desired academic standards. So teachers should develop various teaching learning strategies to make their students to achieve class specific academic standards. We should avoid rote learning methods for the successful implementation of Continuous Comprehensive Evaluation (CCE). It is very important to know more about different methods to assess students' progress by summative and formative evaluation. The new textbooks reflect Continuous Comprehensive Evaluation and teaching method with respect to discussed concepts. This is very useful to teachers and students.

In the new textbooks, the design of concepts and activities help in achieving the specified academic standards and learning outcomes. Teachers need to plan appropriate teaching strategies to improve the academic standards and learning outcomes among the students by the end of teaching the lesson. For effective implementation of continuous comprehensive evaluation the teaching must move away from the methods of rote memorisation of concepts. There is a need for teachers to have a good understanding of the methods of evaluation which help them in assessing the progress of children in a constructive and comprehensive way. The new textbooks are not confined to simply provide necessary informations about concepts. Instead they focus on the new teaching strategies and evaluation techniques which are very important for both teachers and students.

We thank the VidyaBhavan Society, Rajasthan for their cooperation in designing these new text books, the writers for preparing the lessons, the editors for checking the textual matters and the DTP group for cutely composing the textbook. We invite suggestions from educationists, teachers, parents, students and others to make this book more meaningful.

Teachers play a pivotal role in children's comprehensive use of the text book. We hope, teachers will make their best efforts for proper utilization of the text book so as to inculcate scientific thinking among children and inspire them to be great scientists.

**Director,  
SCERT, Hyderabad**



## Dear teachers...

New Science Text Books are prepared in such a way that they develop children's observation power and research enthusiasm. The official documents of National and State Curriculum Frame Works and the Right to Education Act are aspiring to bring gross route changes in science teaching. These textbooks are adopted in accordance with such an aspiration. Hence, science teachers need to adapt to the new approach in their teaching.

In view of this, let us observe certain **Dos** and **Don'ts**:

- There is an immediate need to discard the practices adopted in the schools on a false belief that teaching of 10<sup>th</sup> class means preparing the children for public examination. In 10<sup>th</sup> class the teaching learning process should focus on achieving the academic standards and learning outcomes rather winning race of scoring marks.
- Avoid practices like using guides and question banks, asking the children to read only important questions, focussing on lessons which help in scoring more marks.
- Read the lesson thoroughly before you start teaching and ask the children to read the text. Then initiate a discussion to make the children understand the concepts in the lessons.
- Encourage children to express their own views and ideas while writing the answers. Give weightage to such type of writing in examination.
- Some instructions are given in the textbook regarding the collection of certain information by the teacher. Collect such information and make it available to students.
- In public examination, the weightage will be given to all aspects of the syllabus. Except foreword of the textbook everything else must be treated as a part of the curriculum.
- Textual concepts are presented in two ways: one as the classroom teaching and the other as the laboratory performance.
- Lab activities are part and parcel of a lesson. So, teachers must make the children conduct all such activities during the lesson itself, but not separately.
- Teachers are advised to follow the following teaching steps while transacting lessons-mind mapping, reading lesson and identifying new words by children, performing activities, demonstration and discussion, conclusion and evaluation.
- In the text, some special activities are presented as box items: 'think and discuss, let us do, conduct interview, prepare report, display in wall magazine, participate in Theatre Day, do field observation, organize special days'. To perform all of them is compulsory.
- The abbreviation (A.S.) given at the end of each question in the section "Improve your learning" indicates academic standard.
- Collect information of relevant website addresses and pass on to students so that they can utilize internet services for learning science on their own.
- Plan and execute activities like science club, elocution, drawing, writing poetry on science, making models *etc.* to develop positive attitude among children about environment, biodiversity, ecological balance *etc.*



- As a part of continuous comprehensive evaluation, observe and record children's learning abilities during various activities conducted in classroom, laboratory and field.

We believe, you must have realized that the learning of science and scientific thinking are not mere drilling of the lessons but, in fact, a valuable exercise in motivating the children to explore for solutions to the problems systematically and preparing them to meet life's challenges properly.

### **Dear Students...**

Learning science does not mean scoring good marks in the subject. Competencies like thinking logically and working systematically, learned through it, have to be practiced in daily life. To achieve this, instead of memorizing the scientific theories by rote, one must be able to study them analytically. That means, in order to understand the concepts of science, you need to proceed by discussing, describing, conducting experiments to verify, making observations, confirming with your own ideas and drawing conclusions. This textbook helps you to learn in that way.

What you need to do to achieve such things:

- In 10<sup>th</sup> class the range of concepts is wide. So go through each lesson thoroughly before the teacher actually deals with it.
- Note down the points you came across so that you can grasp the lesson better.
- Think of the principles in the lesson. Identify the concepts you need to know further, to understand the lesson in depth.
- Do not hesitate to discuss analytically about the questions given under the sub-heading 'Think and Discuss' with your friends or teachers.
- You may get some doubts while conducting an experiment or discussing about a lesson. Express them freely and clearly.
- Plan to implement experiment/lab periods together with teachers, to understand the concepts clearly. While learning through the experiments you may come to know many more things.
- Observe how each lesson is helpful to conserve nature. Put what you learnt into practice.
- Analyse how each teaching point has relation with daily life and discuss the things you learned in your science class with farmers, artisans *etc.*
- Work as a group during interviews and field trips. Preparing reports and displaying them is a must. Discuss on the report prepared.
- List out the observations regarding each lesson to be carried through internet, school library and laboratory.
- Whether in note book or exams, write analytically, expressing your own opinions.
- Read books related to your text book, as many as you can.
- You organize yourself the Science Club programs in your school.
- Observe problems faced by the people in your locality and find out what solutions you can suggest through your science classroom.



## ACADEMIC STANDARDS

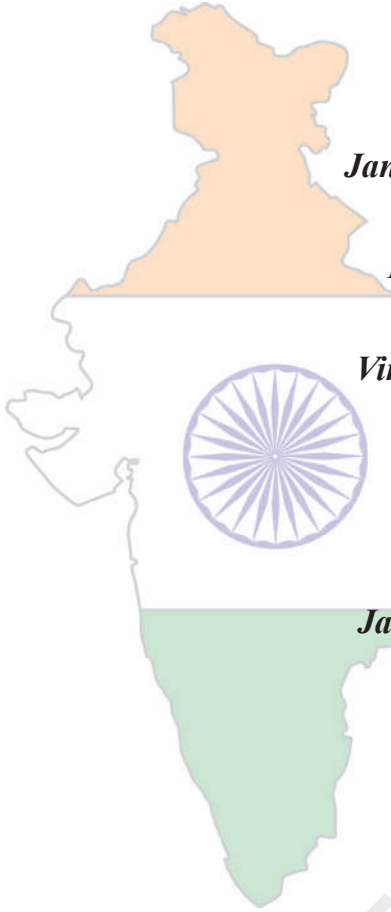
S.No.	Academic Standard	Explanation
1.	<b>Conceptual understanding</b>	Children are able to explain, cite examples, give reasons, and give comparison and differences, explain the process of given concepts in the textbook. Children are able to develop their own brain mappings.
2.	<b>Asking questions and making hypothesis</b>	Children are able to ask questions to understand concepts, to clarify doubts about the concepts and to participate in discussions. They are able to guess the results of an issue with proper reasoning, able to predict the results of experiments.
3.	<b>Experimentation and field investigation.</b>	Children are able to do the experiments given in the text book and developed on their own. Able to arrange the apparatus, record the observational findings, suggest alternative apparatus, takes necessary precautions while doing the experiments, able to do alternate experiments by changing variables. They are able to participate in field investigation and prepare reports.
4.	<b>Information skills and Projects</b>	Children are able to collect information related to the concepts given in the text book by using various methods (eg. interviews, checklist & questionnaire) analyse the information and interpret it. Able to conduct project works.
5.	<b>Communication through drawing, model making</b>	Children are able to communicate their conceptual understanding by the way of drawing pictures labeling the parts of the diagram by drawing graphs, flow charts and making models.
6.	<b>Appreciation and aesthetic sense, values</b>	Children are able to appreciate the nature and efforts of scientists and human beings in the development of science and have aesthetic sense towards nature. They are also able to follow constitutional values
7.	<b>Application to daily life, concern to bio diversity.</b>	Children are able to apply the knowledge of scientific concept they learned, to solve the problem faced in daily life situations. Recognise the importance of biodiversity and takes measures to protect the biodiversity.

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## OUR NATIONAL ANTHEM

- Rabindranath Tagore



*Jana-gana-mana-adhinayaka, jaya he  
Bharata-bhagya-vidhata.  
Punjab-Sindh-Gujarat-Maratha  
Dravida-Utkala-Banga  
Vindhya-Himachala-Yamuna-Ganga  
Uchchhala-jaladhi-taranga.  
Tava shubha name jage,  
Tava shubha asisa mage,  
Gahe tava jaya gatha,  
Jana-gana-mangala-dayaka jaya he  
Bharata-bhagya-vidhata.  
Jaya he! jaya he! jaya he!  
Jaya jaya jaya, jaya he!!*

## PLEDGE

- Pydimarri Venkata Subba Rao

“India is my country; all Indians are my brothers and sisters.  
I love my country, and I am proud of its rich and varied heritage.

I shall always strive to be worthy of it.

I shall give my parents, teachers and all elders respect,  
and treat everyone with courtesy. I shall be kind to animals.

To my country and my people, I pledge my devotion.

In their well-being and prosperity alone lies my happiness.”



# Reflection of light at curved surfaces

In class 7 and 8 you have learnt about the image formation in plane mirrors. You also discussed about the spherical mirrors. You know that why the curved surfaces are known as spherical mirrors.

You might have got many doubts while observing your image in bulged surfaces.

- Is the image formed by a bulged surface same as the image formed by a plane mirror?
- Is the mirror used in automobiles a plane mirror? Why it is showing small images?
- Why does our image appear thin or bulged out in some mirrors?
- Can we see inverted image in any mirror?
- Can we focus sun light at a point using a mirror instead of magnifying glass?
- Are the angle of reflection and angle of incidence also equal for reflection by curved surfaces?

Let us discuss about the reflection of light by spherical mirrors in this lesson to get clarity for the above questions.

## Reflection of light by spherical mirrors

The first law of reflection tells us;

A light ray incident at an angle with the normal at the point of incidence will get reflected making equal angle with the normal.

This law is true for all surfaces, be it a plane surface or a curved one. The important words here are ‘the angle made with normal at the point of incidence’. If for any surface one can decide the normal and find the incident angle, it is possible to deduce the angle made by the reflected ray. It is very easy to find a normal at any point on the plane surface but for a curved or uneven surface it is not straight forward.

### Activity 1

#### Finding the normal to a curved surface

Take a small piece of thin foam or rubber (like the sole of a slipper). Put some pins along a straight line on the foam as shown in the fig.-1(a).

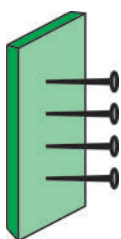


fig-1(a)

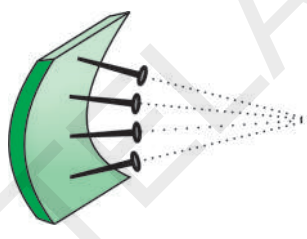


fig-1(b)

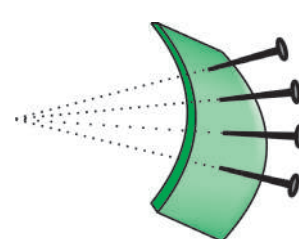


fig-1(c)

All these pins are perpendicular to the plane of foam. If the foam is considered as a mirror, each pin would represent the normal at that point. Any ray incident at the point where the pin makes contact with the surface will reflect with the same angle as the incident ray made with the pin-normal.

Now bend the foam piece inwards as shown in fig.-1(b), what happens to the pins?

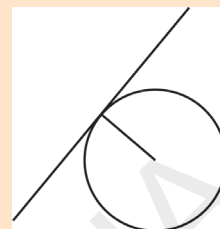
They still represent the normal at various points, but you will notice that all the pins tend to converge at a point (or intersect at a point).

If we bend the foam piece outwards, we will see that the pins seem to move away from each other or in other words they diverge as shown in fig.-1(c).

This gives us an idea of what is likely to happen with a spherical mirror. A concave mirror will be like the rubber sole bent inwards (fig-1(b)) and the convex mirror will be like the rubber sole bent outwards (fig-1(c)).

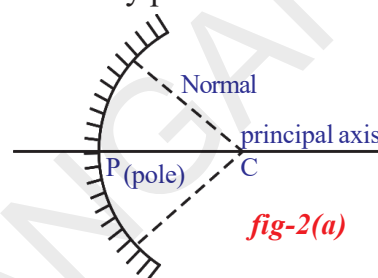
For a concave mirror, like these pins in fig.-1(b), all normals will converge towards a point. This point is called **centre of curvature(C)** of the mirror.

**Recall a little bit of geometry:** while learning about circles and tangents, you have learnt that a radius is always perpendicular to the tangent to the circle drawn at the point.

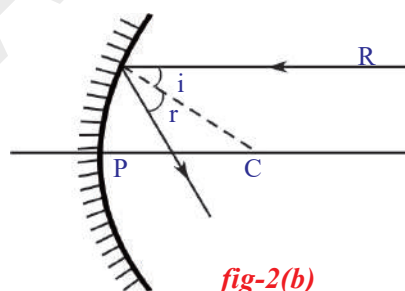


This gives us a clue about how we can find normal to any point on a spherical mirror. All that we have to do is to draw a line from the point on the mirror to centre of the sphere.

It is much easier to imagine this in a two dimensional fig. as shown in fig.-2(a). The concave mirror is actually a part of a big sphere. In order to find this centre point (centre of curvature) we have to think of the centre of the sphere to which the concave mirror belongs. The line drawn from C to any point on the mirror gives the normal at that point.



For the ray R, the incident angle is the angle it makes with the normal shown as  $i$  and the reflected angle is shown as  $r$  in fig.-2(b). We know by first law of reflection  $i = r$ .



The mid point (Geometrical centre) of the mirror is called **pole (P)** of the mirror. The horizontal line shown in the fig.s which passes through the centre of curvature and pole is called **principal axis** of the mirror. The distance between P and C is **radius of curvature (R)** of the mirror.

Try to construct different reflected rays for any array of rays that are parallel to the principal axis as shown in fig. 2(b). What is your conclusion?

### Verifying your drawing with experiment:

To verify this we must first find out some way of obtaining a beam of parallel rays. How do we do that?

First we need to create a situation in which one gets parallel rays of light.

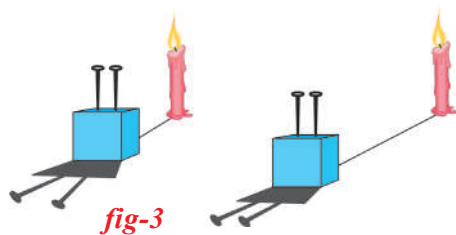


fig-3

In the fig.-3 we have stuck two pins on a thermocole block. The pins are parallel to each other. As we see in the fig., when a source of light is kept very near, we see the shadows diverging (from the base of the pins). As we move the source away from the pins, the angle of divergence gets reduced. If we move the source far away we will get parallel shadows. But as we move the candle away, the light intensity becomes low. That means to get a beam of parallel rays the source should be at a long distance and it must be of sufficient intensity.

Where do we find one such source?

Yes, we have one easily available source, you probably have guessed it: The Sun.

Let us do an experiment with sun rays and a concave mirror.

## Activity 2

Hold a concave mirror such that sunlight falls on it. Take a small paper and slowly move it in front of the mirror and find out the point where you get the smallest and brightest spot, which will be the image of the sun. (See to it that your paper is small so that it does not obstruct the incoming sun rays.)

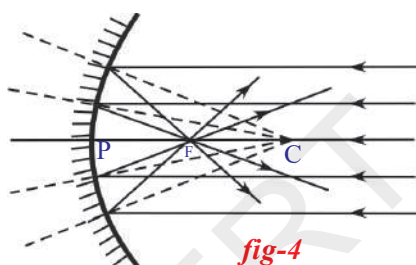


fig-4

The rays coming from the sun parallel to the principal axis of concave mirror converge to a point (see fig.-4). This point is called **Focus or focal point (F)** of the concave mirror. Measure the distance of this spot from the pole of the mirror. This distance is the **focal length (f)** of the mirror. The radius of curvature will be twice this distance ( $R=2f$ ).

Does this help you to verify the conclusions you arrived at, with your drawing?

- What happens if you hold the paper at a distance shorter than the focal length from the mirror and move it away?
- Does the image of the sun become smaller or bigger?

You will notice that the image of the sun first keeps on becoming small, beyond the focal point it keeps on becoming enlarged.

**Note:** while drawing a ray diagram sometimes it is not clear which is the reflecting side of the mirror. Hence we follow a convention of showing lines on the non-reflecting side (coated side).



**Can you draw the same diagram for a convex mirror?**

See fig.-5 The parallel rays appear to diverge after reflection. If we extend the reflected rays backwards they meet at 'F' i.e. focus of the convex mirror.

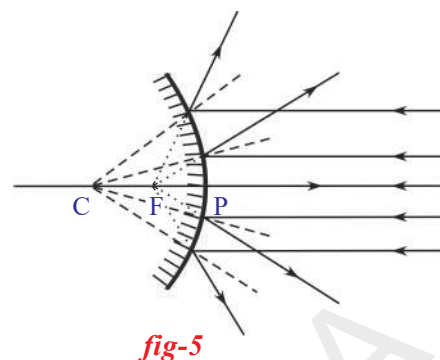


fig-5



### Think and discuss

- See fig.-5. A set of parallel rays are falling on a convex mirror. What conclusions can you draw from this?
- Will you get a point image if you place a paper at the focal point?

When parallel rays are incident on a concave mirror, on reflection they meet at the focus.

- Do we get an image with a concave mirror at the focus every time? Let us find out.



### Lab Activity

**Aim:** Observing the types of images and measuring the object distance and image distance from the mirror.

**Material required:** A candle, paper, concave mirror (known focal length), V-stand, measuring tape or meter scale.

**Procedure:** Place the concave mirror on V-stand, arrange a candle and meter scale as shown in fig.-6.

Keep the candle at different distances from the mirror (10cm to 80cm) along the axis and by moving the paper (screen) find the position where you get the sharp image on paper. (Take care that flame is above the axis of mirror, paper is below the axis).

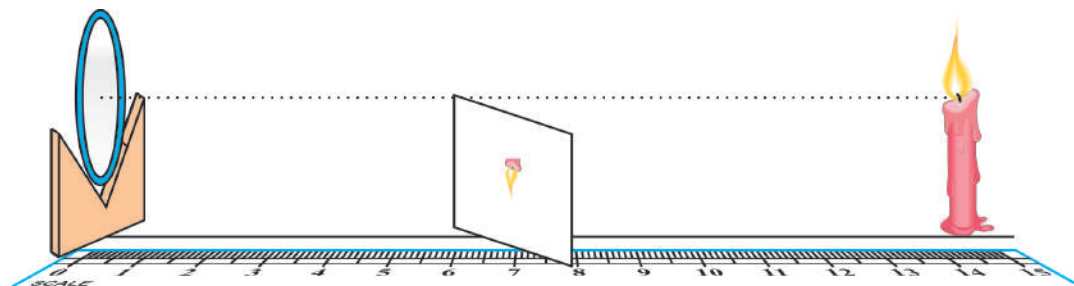


fig-6

Note down your observations in table-1.

**Table-1**

	Distance of candle from mirror (object distance-u)	Distance of paper from mirror (image distance-v)	Enlarged/diminished	Inverted or erect
1				
2				
3				
4				

Group your observations based on the type of image you see (e.g. Image is bigger and inverted). It is possible you may not get any image at some positions, note down that too!

Since we know the focal point and centre of curvature, we can reclassify our above observations as shown in table-2. What do you infer from this table?.

At this point we suggest that you make one more observation. You have been trying to get the image on a paper when the object is at different positions. At the same time also look into the mirror and note your observations about how the image appears.

- Is it inverted or erect, enlarged or diminished?

**Table - 2**

Position of the candle (object)	Position of the image	Enlarged/diminished	Inverted or erect	Real or virtual
Between mirror & F				
At focal point				
Between F and C				
At centre of curvature				
Beyond C				

What do you infer from the table-2?

Let us try to draw ray diagrams with concave mirrors and compare them with your inferences.

### Ray diagrams for concave mirror

In activity-5 we saw the ray diagram of sunrays parallel to the concave mirror and the image of the sun was very small at the focal point

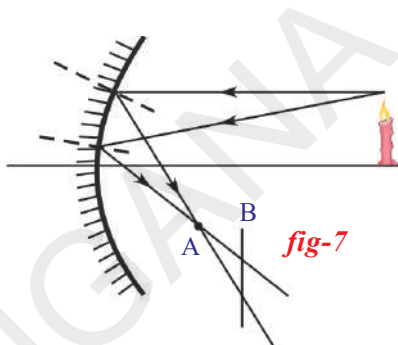
(See fig.-4). Now we shall develop a technique to draw ray diagrams when an object is placed anywhere on the axis of the mirror and validate the above observations.

Here we will take at least two rays originating from the same point on the object but with different direction, see how they get reflected from the mirror and find out the point where they meet to form the image.

Let us take an example.

As shown in the fig.-7, assume a concave mirror and a candle placed at some distance along the axis of the mirror.

The diagram shows two rays coming from the tip of the flame (object). The reflected rays are constructed based on the laws of reflection. They meet at point A. The tip of the flame of the reflected image will be at the point of intersection, A.



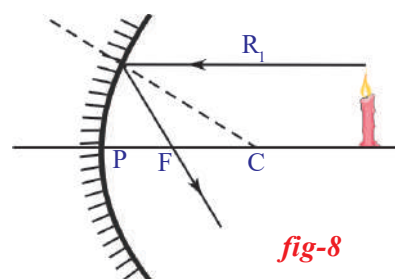
- Why only at point A?

If we hold the screen at any point before or beyond point A (for example at point B), we see that the rays will meet the screen at different points. Therefore, the image of the tip of the flame will be formed at different points due to these rays. If we draw more rays emanating from the same tip we will see that at point A they will meet but at point B they won't. So, the image of the tip of the flame will be sharp if we hold the screen at point A and will become blurred (due to overlapping of multiple images) when we move the paper slightly in any direction (forward or backward). Is this not something that you observed during the previous experiment with sun rays?

However, it is not going to be easy to evaluate the angle of reflection for any arbitrary ray, every time we will have to find the normal, measure the incident angle and construct a ray with equal angle on the other side. This would be a tedious task, can we find any other simpler method?

Yes, there are a few. Based on our discussion so far, we can identify some appropriate rays which we can take as representative rays to find the point 'A'.

We have seen that all rays that are parallel to the axis get reflected such that they pass through the focal point of the mirror. So, for drawing any diagram the most suitable ray to draw will be the one that comes from the object and goes parallel to the axis of the mirror. The reflected ray will be the line drawn from the point of incidence on the mirror and passes through



the focal point of the mirror. To make it more convenient we will always take rays that come from the tip of the object. See the ray  $R_1$  in fig.-8.

The converse situation of previous one is also true; that is, a ray that passes through the focal point of the mirror will travel parallel to the axis after reflection.

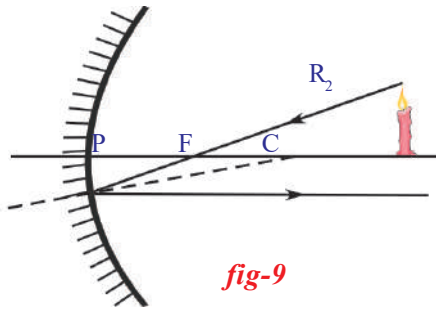


fig-9

This gives us our second ray. This will be the ray coming from the tip of the flame and going through the focal point and falling on the mirror. After reflection, this ray travels parallel to the axis. So we draw the reflected ray as a line parallel to the axis coming from the point where the incident ray meets the mirror. See  $R_2$  in fig.-9.

Using the rays  $R_1$ ,  $R_2$  and finding the point where they intersect we know the point where the image of the tip is formed.

There is one more ray which is convenient to draw.

We have seen earlier that any ray that is normal to the surface, on reflection, will travel along the same path but in the opposite direction. Which ray can such a one be for a spherical mirror?

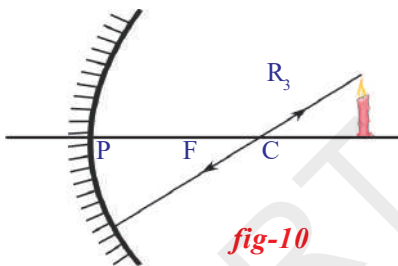


fig-10

We know that a line drawn from the centre of curvature to the mirror is perpendicular to the tangent at the point where the line meets the curve. So if we draw a ray coming from the tip of the object going through the centre of curvature to meet the mirror, it will get reflected along the same line. This ray is shown as  $R_3$  in the fig.-10. In general, a ray travelling along normal retraces its path.

Along with these three rays 'the ray which comes from the object and reaches the pole of the mirror' is also useful in drawing ray diagrams. For this ray, the principal axis is the normal.

If we have our object (candle) placed as shown in fig.-11, we can draw

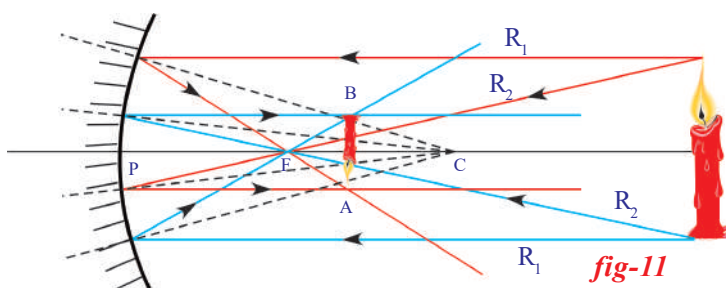


fig-11

the ray diagram to get the point of intersection A, of any two rays coming from the top of the object and point of intersection B, of any two rays coming from the bottom of the object. We notice that

point B is exactly at the same distance from mirror as point A. Hence the image is vertical and inverted.

- Where is the base of the candle expected to be in the image when the candle is placed on the axis of the mirror?

Since any ray coming from any point on the axis and travelling along the axis will get reflected on the axis itself, we can conclude that the base of the image is going to be on the axis. Using the knowledge, that if the object is placed vertically on the axis, the image is going to be vertical, all that we need to do, is to draw a perpendicular from point A to the axis. The intersection point is the point where the base of the image of the candle is likely to be formed. See fig.-12. Hence, as shown in the diagram the image will be inverted and diminished.

Fig.-12 is drawn for the case where the object is placed beyond the centre of curvature.

Does this conclusion match with your observations? (Lab Activity)

Draw similar diagrams for other cases and verify that they match with your observations.

- During the experiment, did you get any positions where you could not get an image on the screen?

Consider the case shown in the fig.-13. The candle object (O) is placed at a distance less than the focal length of the mirror.

The first ray ( $R_1$ ) will start from tip of the object and run parallel to axis to get reflected so as to pass through the focal point. This one is easy to draw. The second ray that we chose for earlier ray diagrams is the ray coming from the tip of the object and going through the focal point but it is not possible as such a ray will not meet the mirror. So we must use the third ray, a ray coming from the tip of the object and going through the centre of curvature.

But that does not seem to be possible. So we make a small change.

Instead of drawing a ray from the candle tip to centre of curvature, we consider a ray that comes from the tip and goes in such a direction that it would go through the centre of curvature if extended backwards. This ray is normal to the surface and so will be reflected along the same line in opposite direction and will go through centre of curvature.

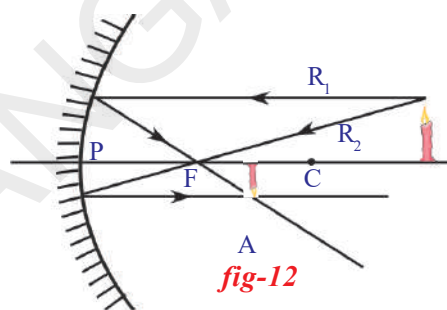


fig-12

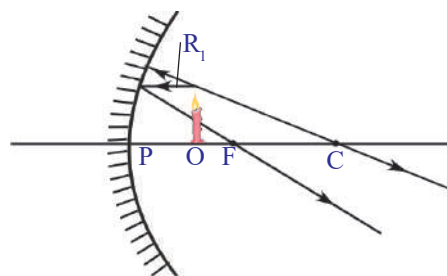


fig-13

We notice that the two reflected rays (fig.-13) diverge and will not meet. While doing the experiments for a case such as this we were unable to find any place where we get a sharp image on the screen. This ray diagram tells us that since the reflected rays are diverging we will not get an image anywhere. So even if we had moved the screen much away from the mirror, we would not have found an image.

In such situations, however, we do see an image when we look in the mirror. Is it possible to explain this image with a ray diagram?

Remember what we did to find the image in a plane mirror. To decide the position of image we extended the reflected rays backwards till they meet. We will do the same here. When we look in the mirror we are looking at these diverging reflected rays. They appear to be coming from one point. We can get this point by extending the rays backwards as shown in fig.-14. The image does not really exist the way we see in other cases, but it is visible to us.

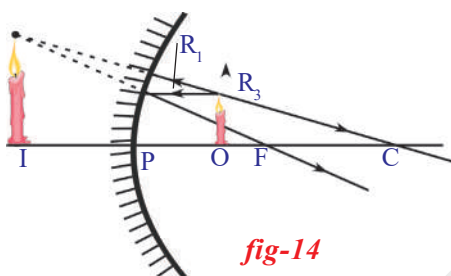


fig-14

As seen in the fig.-14, the image will be erect and enlarged. Does this match with your observations?

This image that we get by extending the rays backwards is called a **virtual image**. We cannot get this on a screen like a **real image**.

The case in which the object is at the centre of curvature is another interesting situation. See fig.-15.

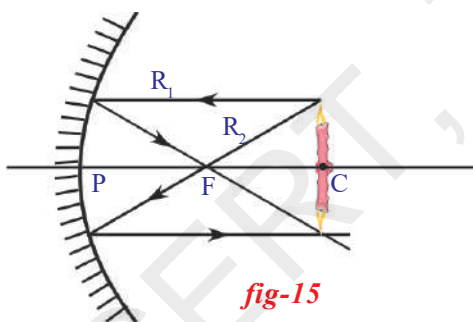


fig-15

From the ray diagram (fig.-15) we conclude that the image of the object will be formed at the same distance as the object and it will be inverted and of the same size. What is your observation?



### Think and discuss

Do you get an image when object is placed at F?  
Draw a ray diagram. Do the experiment.

From the ray diagrams and the observations you may have noticed some peculiar properties of concave mirrors. They enlarge the image when the object is held close to the mirror (less than the focal length). Also, the image is erect. This property is used at many places and most commonly in shaving mirrors and mirrors used by dentists.

Another property is the way that it can converge the rays to its focal point. This is extensively used in many places. Look at the shape of TV dish antennas.

If you look around you will see many curved surfaces but all surfaces are not concave, many of these are convex.

Have you observed the rear view mirrors of a car?

What type of surface do they have?

Have you observed images formed on the rear and window glasses of a car? What type of surfaces are these? See fig. -16.



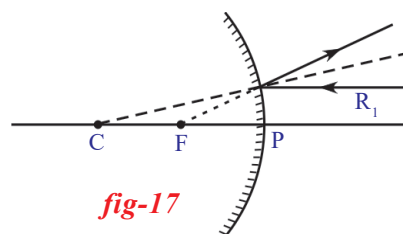
*fig-16*

Can we draw ray diagrams for convex surfaces?

### Ray diagrams for convex mirrors

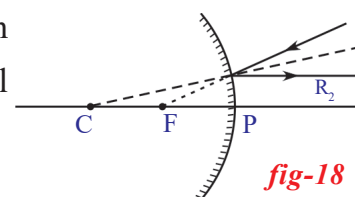
One can draw ray diagrams for a convex mirror too. The 'easy' rays that we identified earlier can be used in this case with small modification. Here there are three rules which describe these rays. The procedure for drawing the diagram is similar and is not repeated here.

**Rule 1:** A ray parallel to the axis, on meeting the convex mirror will get reflected so as to appear as if it is coming from the focal point. See fig.-17.



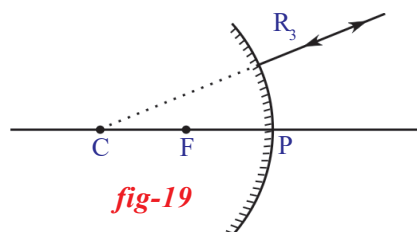
*fig-17*

**Rule 2:** This is converse of Rule 1. A ray travelling in the direction of the focal point, after reflection, will become parallel to the axis. See fig.-18.



*fig-18*

**Rule 3:** A ray travelling in the direction of the centre of curvature will, on reflection, travel in the opposite direction and appears to be coming from the centre of curvature. See fig.-19.



*fig-19*

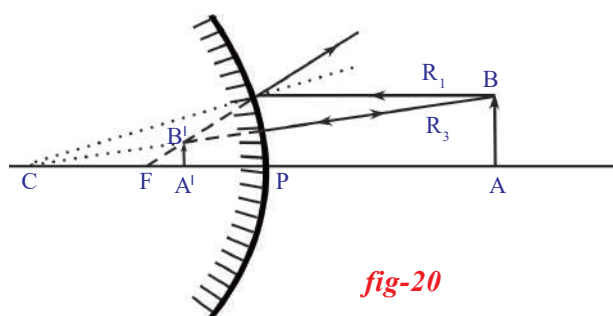


fig-20

Now let us use these rules to show the formation of images when the object is placed at different places in front of the convex mirror (see fig.-20)

AB is the object placed at any point on the principal axis in front of the convex mirror. Using Rule (1) and Rule (3), we get an erected, diminished, and virtual image between P and F on the back side of the mirror. This image can not be caught on screen and visible only in the mirror. Hence this is a virtual image. Verify this with an experiment.

Using these rules, draw ray diagrams to show formation of images when an object is placed at different positions and note down your conclusions. Verify your results experimentally.

You may get the image at a particular distance when you place the object at a certain distance. Do you find any relation between the object distance( $u$ ) and the image distance( $v$ )?

### Derivation of formula for curved mirrors

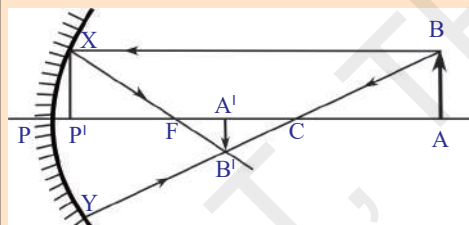


fig-21

Observe fig. 21.

The ray from the tip (B) of the object AB is emanating parallel to principle axis and striking the mirror at X. This ray passes through F after reflection. Another ray starting from B, passes through centre of curvature (C) and strikes the mirror at Y. This ray returns back in the same direction after reflection.

There two rays  $XB'$  and  $YB'$  are meeting at  $B'$ . So  $B'$  is the image of B. Hence the image of AB is  $A'B'$ .

From the above fig. - 21.

$\triangle ABC$  and  $\triangle A'B'C$  are similar triangles

$$\frac{AB}{A'B'} = \frac{AC}{A'C} \quad \dots (1)$$

Draw a line  $XP'$  perpendicular to the principle axis.

Similar  $\triangle P'XF$  and  $\triangle A'B'F$  are similar triangles

$$\frac{P'X}{A'B'} = \frac{P'F}{A'F} \quad \dots (2)$$



From the fig. - 21, we can say that  $P^I X = AB$

$$\frac{AB}{A^I B^I} = \frac{P^I F}{A^I F} \quad \dots (3)$$

from the equations (1), (3) we can write

$$\frac{AC}{A^I C} = \frac{P^I F}{A^I F} \quad \dots (4)$$

If the paraxial rays (rays which are travelling very near to principal axis) are considered, we can say that  $P^I$  coincides with P

Then  $P^I F = PF$

$$\frac{AC}{A^I C} = \frac{PF}{A^I F} \quad \dots (5)$$

We can observe from fig. 21, that

$$AC = PA - PC$$

$$A^I C = PC - PA^I$$

$$A^I F = PA^I - PF$$

by substituting these in equation (5)

$$\frac{PA - PC}{PC - PA^I} = \frac{PF}{PA^I - PF} \quad \dots (6)$$

we know that  $PA = u$ ,  $PC = R = 2f$ ,  $PA^I = v$ ,  $PF = f$

$$\frac{u - 2f}{2f - v} = \frac{f}{v - f}$$

$$(u - 2f)(v - f) = f(2f - v)$$

$$uv - uf - 2vf + 2f^2 = 2f^2 - vf$$

$$uv = 2f^2 - vf + uf + 2vf - 2f^2$$

$$uv = uf + vf \quad \dots (7)$$

Divide equation (7) with  $uvf$

$$\frac{uv}{uvf} = \frac{uf}{uvf} + \frac{vf}{uvf}$$

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

The relation is  $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$  which is known as mirror formula. While using this formula, we have to use sign convention in every situation.

### Sign convention for the parameters related to the mirror equation

1. All distances should be measured from the pole.
2. The distances measured in the direction of incident light, to be taken positive and those measured in the direction opposite to incident light to be taken negative.
3. Height of object ( $h_o$ ) and height of image ( $h_i$ ) are positive if measured upwards from the axis and negative if measured downwards.

Now let us understand magnification, i.e. the relation between the size of the object and the size of the image.

### Magnification (m)

The image formed by a spherical mirror varies in size, here we discuss the variation in height only.

Observe fig. 22.

A ray coming from  $O^I$  is incident at pole with an angle of incidence  $\theta$ , and get reflected with same angle  $\theta$ .

From fig. 22 we can say that  $\Delta POO^I$  and  $\Delta PII^I$  are similar triangles. So

$$\frac{PI^I}{OO^I} = \frac{PI}{PO} \dots\dots\dots(1)$$

according to sign convention

$$PO = -u; \quad PI = -v; \quad OO^I = h_o; \quad PI^I = -h_i$$

Substituting the above values in equation (3).

$$\frac{-h_i}{h_o} = \frac{-v}{-u} \Rightarrow \frac{h_i}{h_o} = \frac{-v}{u}$$

$$\therefore \text{Magnification } m = \frac{h_i}{h_o} = \frac{-v}{u}$$

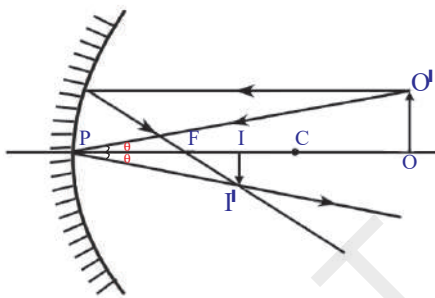


fig-22

We define the magnification,

$$m = \frac{\text{height of image}(h_i)}{\text{height of object}(h_o)}$$

In all cases it can be shown that

$$m = -\frac{\text{image distance}(v)}{\text{object distance}(u)}$$

Calculate the magnifications with the information you have in table-2, for all the five cases.

### Example

An object 4cm in size, is placed at 25cm in front of a concave mirror of focal length 15cm. At what distance from the mirror would a screen be placed in order to obtain a sharp image? Find the nature and the size of the image.

## Solution

According to sign convention:

$$\text{focal length } (f) = -15\text{cm}$$

$$\text{object distance } (u) = -25\text{cm}$$

$$\text{object height } (h_o) = +4\text{cm}$$

$$\text{image distance } (v) = ?$$

$$\text{image height } (h_i) = ?$$

Substitute the above values in the equation

$$\left(\frac{1}{f}\right) = \left(\frac{1}{u}\right) + \left(\frac{1}{v}\right)$$

$$\left(\frac{1}{-15}\right) = \frac{1}{v} + \frac{1}{-25} \quad \Rightarrow \quad \frac{1}{v} = \left(\frac{1}{25}\right) - \frac{1}{15}$$

$$\frac{1}{v} = \frac{-2}{75}$$

$$\Rightarrow v = -37.5\text{cm}$$

So the screen should be placed at 37.5cm from the pole of the mirror.

The image is real.

$$\text{magnification } m = \frac{h_i}{h_o} = \frac{-v}{u}$$

by substituting the above values  $\frac{h_i}{4} = \frac{-(-37.5)}{(-25)}$

$$h_i = \frac{-(37.5 \times 4)}{(25)}$$

$$h_i = -6\text{cm}$$

So, the image is inverted and enlarged.

We have learnt the phenomenon of reflection of light by curved mirrors.

Let us make use of it in our daily life.

## Making of solar cooker

You might have heard the story of **Archimedes** burning ships using mirrors.

Can we at least heat up a vessel using a mirror?

Let us try:

We have already learnt that a concave mirror focuses parallel sun rays at the focal point of the mirror. So with a small concave mirror we can heat up and burn paper as shown in the fig.-23. (Try this with convex mirror also. What do you observe?)

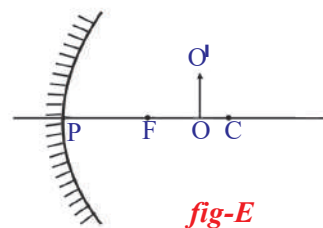


fig-E

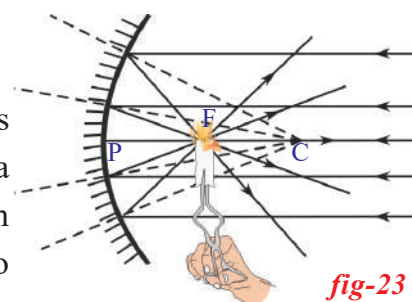


fig-23

In the same way make a big concave mirror to heat up a vessel.

You might have observed the TV dish antenna. Make a wooden/ iron frame in the shape of TV dish. Cut acrylic mirror sheets in to 8 or 12 pieces in the shape of isosceles triangles with a height equal to the radius of your dish antenna. The bases of 8 or 12 triangles together make the circumference of the dish. Stick the triangle mirrors to the dish as shown in fig.-24.



fig-24

Your solar heater/cooker is ready.

Arrange it so that concave part faces sun. Find its focal point and place a vessel at that point. The vessel gets heated enough to cook rice.

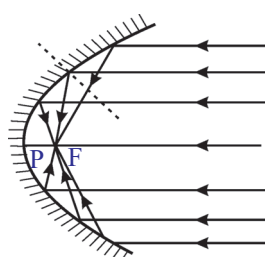


fig-25

In practical applications (like in car-headlights), concave mirrors are of parabolic shape (see fig. 25)



### Key words

*centre of curvature, radius of curvature, principal axis, pole, focus/focal point, focal length, object distance, image distance, virtual image, real image, magnification*



### What we have learnt

- Normal to the curved surface at a point on it is the line joining the centre of curvature and that point.

- **Mirror formula:**  $\left(\frac{1}{f}\right) = \left(\frac{1}{v}\right) + \left(\frac{1}{u}\right)$

- Magnification  $m = \left(\frac{\text{size of the image}}{\text{size of the object}}\right) = \left(\frac{h_i}{h_o}\right)$  (or)

$$m = -\left(\frac{\text{image distance}}{\text{object distance}}\right) = -\left(\frac{v}{u}\right)$$

- The image formed by actual intersection of reflection rays is called real image. This can be caught on screen.
- The image formed by controlled rays of reflection is called virtual image. It can not be caught on screen.

Position of the candle (object)	Position of the image	Enlarged?/ diminished?	Inverted or erect	Real or virtual
Between mirror & F	Behind the mirror	Enlarged	Erect	Virtual
On focal point	At infinity	-	-	-
Between F and C	Beyond C	Enlarged	Inverted	Real
On centre of curvature	At C	Same size	Inverted	Real
Beyond C	Between F and C	Diminished	Inverted	Real
At infinity	At focus	point	-	Real



## Improve your learning



### I. Reflections on concepts

1. Where will the image be formed when we place an object on the principal axis of a concave mirror at a point between focus and centre of curvature?(AS<sub>1</sub>)
2. State the differences between convex and concave mirrors? (AS<sub>1</sub>)
3. Distinguish between real and virtual images. (AS<sub>1</sub>)
4. How do you get a virtual image using a concave mirror? (AS<sub>1</sub>)
5. What do you know about the terms given below related to spherical mirrors? (AS<sub>1</sub>)
  - a) Pole
  - b) Centre of curvature
  - c) Focus
  - d) Radius of curvature
  - e) Focal length
  - f) Principal axis
  - g) Object distance
  - h) Image distance
  - i) Magnification
6. What do you infer from the experiment which you did to measure the object distance and image distance? (AS<sub>3</sub>)

### II. Application of concepts

1. Find the distance of the image when an object is placed on the principal axis at a distance of 10 cm in front of a concave mirror whose radius of curvature is 8 cm. (AS<sub>1</sub>)
2. The magnification product by a mirror is +1. What does it mean?(AS<sub>1</sub>)

- If the spherical mirrors were not known to human beings, guess the consequences. (AS<sub>2</sub>)
- Draw suitable rays by which we can guess the position of image formed by a concave mirror? (AS<sub>5</sub>)
- Show the formation of image with a ray diagram when an object is placed on the principal axis of a concave mirror away from the centre of curvature? (AS<sub>5</sub>)
- Why do we prefer a convex mirror as a rear-view mirror in the vehicles? (AS<sub>7</sub>)

### III. Higher Order Thinking Questions

- A convex mirror with a radius of curvature of 3 m is used as rear view mirror for a vehicle. If a bus is located at 5 m from this mirror, find the position, nature and size of the image? (AS<sub>7</sub>)
- To form the image on the object itself, how should we place the object in front of a concave mirror? Explain with a ray diagram? (AS<sub>5</sub>)

### Multiple choice questions

#### IV. Multiple choices questions

- If an object is placed at C on the principal axis in front of a concave mirror, the position of the image is [      ]  
 a) at infinity      b) between F and C      c) at C      d) beyond C
- We get a diminished image with a concave mirror when the object is placed [      ]  
 a) at F      b) between the pole and F      c) at C      d) beyond C
- We get a virtual image in a concave mirror when the object is placed [      ]  
 a) at F      b) between the pole and F      c) at C      d) beyond C
- Which of the following represents Magnification 'm'  
 i)  $\frac{v}{u}$       ii)  $\frac{-v}{u}$       iii)  $\frac{h_i}{h_0}$       iv)  $\frac{h_0}{h_i}$  [      ]  
 a) (i) & (ii)      b) (ii) & (iii)      c) (iii) & (iv)      d) (iv) & (i)
- Ray which seems to be travelling through the focus of a convex mirror, path of the reflected ray of an incident [      ]  
 a) parallel to the axis      b) along the same path in opposite direction  
 c) through F      d) through C



# Chemical Equations



We had discussed in the previous classes on different changes that occur around us and we have classified those changes into Physical and Chemical changes.

Now, just think about the changes involved in the following processes in our daily life.

- The process of digestion.
- Burning of the crackers.
- The process of Respiration.
- Powdered lime added to water.
- Ripening of the Mango.
- Exposing iron nails to moisture in air for longer period.

What changes do you notice? Are they physical changes or chemical changes? Are they temporary changes or permanent changes?

In all the above processes, the nature of original substance would be changed. If new substances are formed with properties completely unlike to those of the original substances, we say that a chemical change has taken place.

- How do we know that a chemical reaction has taken place?

Let us perform some activities to know this.



## Activity 1

Take about 1 g of quick lime (calcium oxide) in a beaker. Add 10 ml of water to this. Touch the beaker with your finger.

- What do you notice?

You notice that the beaker is hot. The reason is that the calcium oxide (quick lime) reacts with water with the liberation of heat energy. Calcium oxide dissolves in water producing colourless solution. Test the nature of solution with litmus papers.

- What is the nature of the solution?

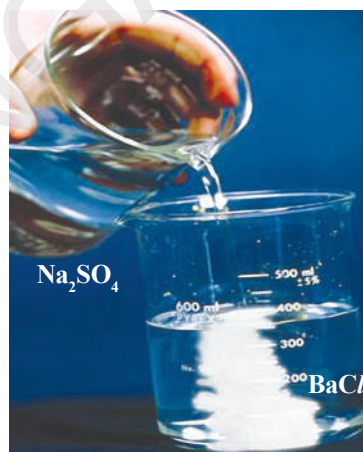
A red litmus paper turns blue when dipped in the above solution. A blue litmus does not change its colour. Hence, the solution is a basic solution.

## Activity 2

Take about 100 ml of water in a beaker and dissolve a small quantity of sodium sulphate ( $\text{Na}_2\text{SO}_4$ ).

Take about 100ml of water in another beaker and dissolve a small quantity of barium chloride ( $\text{BaCl}_2$ ). Observe the colours of the solutions obtained.

- What are the colours of the above solutions?
- Can you name the solutions obtained?  
Add  $\text{Na}_2\text{SO}_4$  solution to  $\text{BaCl}_2$  solution and observe.
- Do you observe any change on mixing these solutions?



*fig-1: Formation of barium sulphate precipitate*

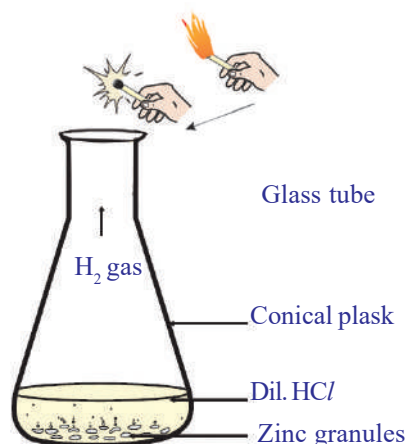
## Activity 3

Take some zinc granules in a conical flask. Add about 20 ml of dilute hydrochloric acid to the zinc granules in the conical flask.

Observe the changes in the conical flask.

- What changes do you notice?  
Now keep a burning match stick near the mouth of the conical flask.
- What happens to burning match stick?
- Touch the bottom of the conical flask with your fingers. What do you notice?
- Is it hot?

From the above activities you can conclude that during a chemical change:



*fig-2: Formation of hydrogen gas by the action of dilute HCl on zinc and testing of  $\text{H}_2$  gas*

1. The original substances lose their characteristic properties. Hence these may be products with different physical states and colours.
2. Chemical changes may be exothermic or endothermic i.e, heat may be liberated or absorbed.
3. They may form an insoluble substance known as precipitate.
4. Gas may be evolved

In our daily life we observe variety of changes taking place around us. In this chapter we study various types of chemical reactions and their symbolic representation.

## Chemical Equations

In activity 1, when calcium oxide reacts with water a new substance is formed which is unlike to either calcium oxide or water. The description of chemical reactions in a sentence in activity-1 is quite long. It can be written in shorter form as a word equation.

The word equation of the above reaction is,  
 calcium oxide + water → calcium hydroxide ..... (1)  
 (Reactants) (Product)

The substances which undergo chemical change in the reaction are called *reactants* and the new substances formed are called *products*.

A chemical reaction written in the form of word equation shows the change of reactants to products by an arrow placed between them. The **reactants**, are written on the left side of the arrow and the final substances, or **products** are written on the right side of the arrow. The arrow head point faces the products showing the direction of the reaction.

If there is more than one reactant or product involved in the reaction, they are indicated with a plus (+) sign between them.

## Writing a Chemical Equation

- Can you write a chemical reaction in any other shorter way other than the way we discussed above?

Chemical equations can be made more precise and useful if we use chemical formulae instead of words.

Generally, a compound is written by giving its **chemical formula**, which lists the symbols of the constituent elements and uses the subscript to indicate the number of atoms of each element present in the compound. If no subscript is written the number 1 is understood. Thus we can write

calcium oxide as CaO, water as H<sub>2</sub>O and the compound formed by the reaction of these two compounds is calcium hydroxide Ca(OH)<sub>2</sub>.

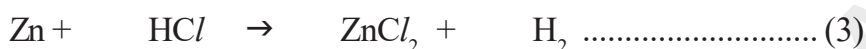
Now the reaction of calcium oxide with water can be written as:



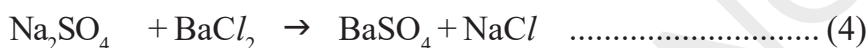
In the above chemical equation, count the number of atoms of each element on left side and right side of arrow.

- Is the number of atoms of each element are equal on both sides?

Observe the following reactions and their chemical equations. Zinc metal reacts with dilute HCl to yield ZnCl<sub>2</sub> and liberates Hydrogen gas.



Sodium sulphate reacts with barium chloride to give white precipitate, barium sulphate and sodium chloride.



- Do the atoms of each element on left side equal to the atoms of the element on the right side of the equation?

### THINK AND WRITE

You have brushed the wall with an aqueous suspension of Ca(OH)<sub>2</sub>. After two days the wall turned to white colour.

- Write the balanced chemical reactions for the above changes using the appropriate symbols and formulae?.

## Balancing Chemical Equations

According to the law of conservation of mass, the total mass of the products formed in chemical reaction must be equal to the total mass of reactants consumed. You know that an atom is the smallest particle of an element that takes part in a chemical reaction. It is the atom which accounts for the mass of any substance. As per the law of conservation of mass the number of atoms of each element before and after reaction must be the same.

All the chemical equations must be balanced, because atoms are neither created nor destroyed in chemical reactions. A chemical equation in which the number of atoms of different elements on the reactant side (left side) are same as those on product side (right side) is called a *balanced reaction*.

**Formula units:** Balancing a chemical equation involves finding out how many **formula units** of each substance take part in the reaction.as the

name implies, is one unit – whether atom, ion or molecule – corresponding to a given formula. One formula unit of NaCl for example is one Na<sup>+</sup> (Sodium ion) and one Cl<sup>-</sup> (Chlorine ion); one formula unit of MgBr<sub>2</sub> is one Mg<sup>2+</sup> ion and two Br<sup>-</sup> ions and one formula unit of water is one H<sub>2</sub>O molecule.

Now let us balance the chemical equation using a systematic method. For this take the example of hydrogen reacting with oxygen to form water.

**Step 1:** Write the equation with the correct chemical formulae for each reactant and product.

**Eg:** In the reaction of hydrogen with oxygen to yield water, you can write chemical equations as follow:

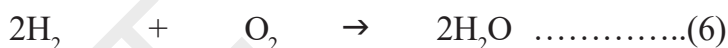
Element	No of atoms	
	LHS	RHS
H	2	2
O	2	1



**Step 2:** After writing the molecular formulae of the substances the equation is to be balanced. For this we should not touch the ratio of atoms in the molecules of the substances but we may assign

suitable numbers as the coefficients before the formulae.

In the above equation write '2' before the molecular formula of hydrogen and also '2' before the molecular formula of water. Observe whether atoms of both the elements hydrogen and oxygen are same (or) different on both the sides. They are in the same number on both sides. Therefore, the equation is balanced.



**Step 3:** Sometimes there is a possibility that the coefficients of all the substances getting divided with a suitable number. Since we require the lowest ratio of coefficient for reactants and products the above operation is to be done. If no common factor is there, there is no need to divide the equation. The above equation needs no division of the coefficients of the substances.

**Step 4:** Verify the equation for the balancing of atoms on both sides of the equations. The above equation (6) is a balanced equation.

Let us work out some more examples to see how equations are balanced.

### **Eg-1: Combustion of propane (C<sub>3</sub>H<sub>8</sub>)**

Propane, C<sub>3</sub>H<sub>8</sub> is a colourless, odourless gas often used as a heating and cooking fuel. Write the chemical equation for the combustion reaction of propane. The reactants are propane and oxygen and the products are

carbon dioxide and water.

Write the reaction in terms of symbols and formulae of the substances involved and follow the four steps described in previous discussion.

**Step 1:** Write the unbalanced equation using correct chemical formulae for all substances.

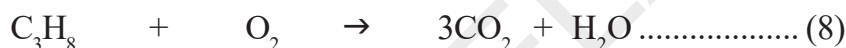


**Note:** Unbalanced chemical equation containing molecular formulae of the substances is known as *skeleton equation*.

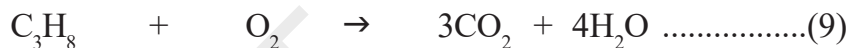
**Step 2:** Compare number of atoms of each element on both sides.

Find the coefficients to balance the equation. It is better to start with the most complex substance – in this case  $\text{C}_3\text{H}_8$ . Look at the skeleton equation, and note that there are 3 carbon atoms on the left side of the equation but only 1 on the right side. If we add a coefficient of 3 to  $\text{CO}_2$  on the right side the carbon atoms get balanced.

Element	No of atoms	
	LHS	RHS
C	3 (in $\text{C}_3\text{H}_8$ )	1 (in $\text{CO}_2$ )
H	8 (in $\text{C}_3\text{H}_8$ )	2 (in $\text{H}_2\text{O}$ )
O	2 (in $\text{O}_2$ )	3 (in $\text{CO}_2, \text{H}_2\text{O}$ )



Now, look at the number of hydrogen atoms. There are 8 hydrogens on the left but only 2 on the right side. By adding a coefficient of 4 to the  $\text{H}_2\text{O}$  on the right, the hydrogen atoms get balanced.



Finally, look at the number of oxygen atoms. There are 2 on the left side but 10 on the right side, by adding a coefficient of 5 to the  $\text{O}_2$  on the left, the oxygen atoms get balanced.



**Step 3:** Make sure the coefficients are reduced to their smallest whole-number values. In fact, the equation (10) is already with the coefficients in smallest whole number. There is no need to reduce its coefficients, but this might not be achieved in each chemical reaction.

Let us assume that you have got chemical equation as shown below:



- Is it a balanced equation as per rules?
- How do you say?

Though the equation (11) is balanced, the coefficients are not the smallest whole numbers. It would be necessary to divide all coefficients of equation (11) by 2 to reach the final equation.



**Step 4:** Check the answer. Count the numbers and kinds of atoms on both sides of the equation to make sure they are the same.

**Eg-2:**

Iron oxide reacts with Aluminum to form iron and Aluminum trioxide. Write the chemical equation to show the reaction and balance it.

**Step 1:** Write the equation using the correct chemical symbols and formulae for all the reactants and products.



**Step 2:** Find the suitable coefficient for the reactants and products, to equate the number of atoms of each element on both sides.

i. Examine the number of atoms of each element present in equation (13) on both sides.

Elements	No. of atoms in reactants	No. of atoms in products
Fe	2 (in Fe <sub>2</sub> O <sub>3</sub> )	1 (in Fe)
O	3 (in Fe <sub>2</sub> O <sub>3</sub> )	3 (in Al <sub>2</sub> O <sub>3</sub> )
Al	1 (in Al)	2 (in Al <sub>2</sub> O <sub>3</sub> )

In the above equation (13), Number of oxygen atoms is equal on both sides. We have to balance the remaining atoms.

ii. There are 2 Fe atoms on left side(on reactant side). There is one Fe atom on right side(on products side). To equate number of Fe atoms, multiply Fe by 2 on product side.

Now the partially balanced equation is:



iii. In the above equation(14) number of Aluminum atoms still unbalanced.

There is one 'Al' atom on left side and 2 'Al' atoms on the right side (in Al<sub>2</sub>O<sub>3</sub>), to balance 'Al' atoms on both sides multiply 'Al' by 2 on left side of arrow mark.

Now the partially balanced equation:



The above equation(15), the number of atoms of each element is same on both sides of arrow mark. This is a balanced chemical equation.

**Step 3:** The above equation(15) is balanced and coefficients are also smallest whole numbers.

**Step4:** Finally to check the correctness of balanced equation, count the number of atoms of each element on both sides of equation.



Elements	No of Atoms of Reactants	No. of Atoms in products
Fe	2 (in Fe <sub>2</sub> O <sub>3</sub> )	2(in Fe)
O	3 (in Fe <sub>2</sub> O <sub>3</sub> )	3(in Al <sub>2</sub> O <sub>3</sub> )
Al	2 (in 2 Al)	2(in Al <sub>2</sub> O <sub>3</sub> )

**(Note:** The above method of balancing is called trial and error method only. Sometimes you may have to take more care to balance the equation.)

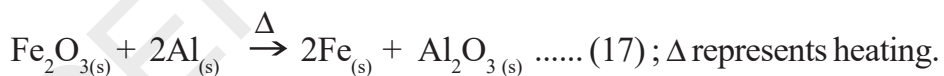
### Making Chemical Equations more informative:

Chemical equations can be made more informative by expressing following characteristics of the reactants and products.

- i. Physical state
- ii. Heat changes (exothermic or endothermic change)
- iii. Gas evolved (if any)
- iv. Precipitate formed (if any)

**i. Expressing the physical state:** To make the chemical equation more informative, the physical states of the substances may be mentioned along with their chemical formulae. The different states ie., gaseous, liquid, and solid states are represented by the notations (g), (l) and (s) respectively. If the substance is present as a solution in water, the word 'aqueous' is written. In the short form it is written as (aq).

The balanced equation(16) is written along with the physical states as:

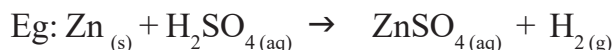


**ii. Expressing the heat changes:** Heat is liberated in exothermic reactions and heat is absorbed in endothermic reactions. See the following examples.

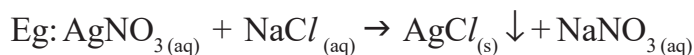
1. C<sub>(s)</sub> + O<sub>2(g)</sub> → CO<sub>2(g)</sub> + Q (exothermic reaction)
2. N<sub>2(g)</sub> + O<sub>2(g)</sub> → 2NO<sub>(g)</sub> - Q (endothermic reaction)

'Q' is *heat energy* which is shown with *plus* (+) sign on product side for exothermic reactions and *minus* (-) sign on product side for endothermic reactions.

**iii. Expressing the gas evolved:** If a gas is evolved in a reaction, it is denoted by an upward arrow '↑' or (g)

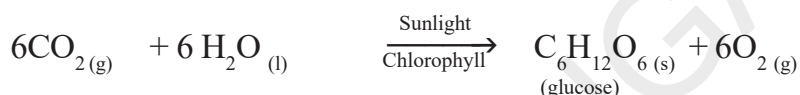
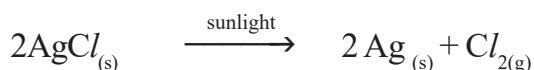


**iv. Expressing precipitate formed:** If a precipitate is formed in the reactions it is denoted by a downward arrow ↓.



Sometimes the reaction conditions such as temperature, pressure, catalyst etc., are indicated above and/or below the arrow in the equation.

For example,



### Interpreting a balanced chemical equation

**i.** A chemical equation gives information about the reactants and products through their symbols and formulae.

**ii.** It gives the ratio of molecules of reactants and products.

**iii.** As molecular masses are expressed in 'Unified Masses' (U), the relative masses of reactants and products are known from the equation.

**iv.** If the masses are expressed in grams then the equation also gives the molar ratios of reactants and products.

**v.** If gases are involved, we can equate their masses to their volumes and calculate the volumes or those gases liberated at given condition of temperature and pressure using molar mass and molar volume relationship.

**vi.** Using molar mass and Avagadro's number we can calculate the number of molecules and atoms of different substances from the equation.

It gives information about relative masses of reactants and products.

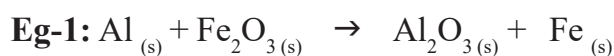
from the equation we get,

a) mass - mass relationship

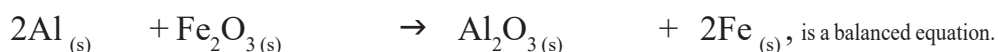
b) mass - volume relationship

c) volume - volume relationship

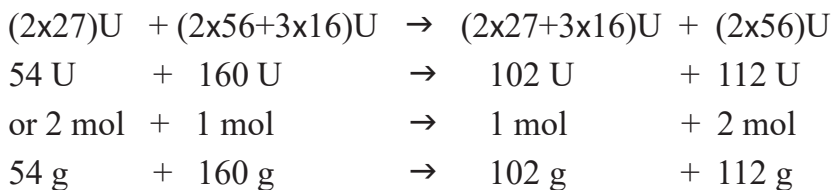
d) mass - volume - number of molecules relationship etc.,



(atomic masses of Al = 27U, Fe = 56U, and O = 16U)

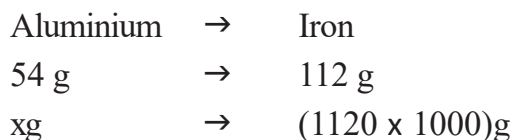






Suppose that you are asked to calculate the amount of aluminium, required to get 1120 kg of iron by the above reaction.

**Solution:** As per the balanced equation

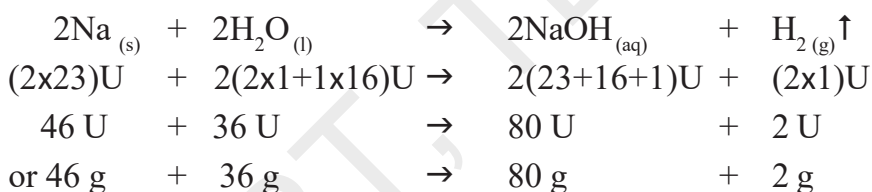


$$\begin{aligned}
 \therefore x \text{ g} &= \frac{(1120 \times 1000) \text{ g} \times 54 \text{ g}}{112 \text{ g}} \\
 &= 10000 \times 54 \text{ g} \\
 &= 540000 \text{ g or } 540 \text{ kg}
 \end{aligned}$$

$\therefore$  to get 1120 kg of iron we have to use 540 kg of aluminium.

**Eg-2:** Calculate the volume, mass and number of molecules of hydrogen liberated when 230 g of sodium reacts with excess of water at STP. (atomic masses of Na = 23U, O = 16U, and H = 1U)

The balanced equation for the above reaction is,



**Solution:** As per the balanced equation:

46 g of Na gives 2g of hydrogen

230g of Na gives \_\_\_\_\_? g of hydrogen.

$$\frac{230 \text{ g} \times 2 \text{ g}}{46 \text{ g}} = 10 \text{ g of hydrogen}$$

1 gram molar mass of any gas at STP i.e, standard temperature 273K and standard pressure 1 bar (760 mm of Hg) occupies 22.4 litres known as *gram molar volume*.

$\therefore$  2.0g of hydrogen occupies 22.4 litres at STP.

10.0g of hydrogen occupies .....? litres at STP.

$$\frac{10.0 \text{ g} \times 22.4 \text{ litres}}{2.0 \text{ g}} = 112 \text{ litres}$$

2 g of hydrogen i.e, 1 mole of  $H_2$  contains  $6.02 \times 10^{23}$  ( $N_A$ ) molecules  
 10 g of hydrogen contain .....

$$\frac{10.0\text{g} \times 6.02 \times 10^{23} \text{ molecules}}{2.0\text{g}}$$

$$= 30.10 \times 10^{23} \text{ molecules}$$

$$= 3.01 \times 10^{24} \text{ molecules}$$

Eg 3- Calculate the volume and No. of molecules of  $CO_2$  liberated at STP. If 50 g. of  $CaCO_3$  is treated with dilute hydrochloric acid which contains 7.3 g of dissolved  $HCl$  gas.

The Chemical equation for the above the reaction is



As per the metric stoichiometric equation 100g of  $CaCO_3$  reacts with 73g of  $HCl$  to liberate 44 g of  $CO_2$

In the above problem the amount of  $CaCO_3$  taken is 50g and  $HCl$  available is 7.3g.

100g of  $CaCO_3$  require 73g of  $HCl$  and 50g of  $CaCO_3$  required 36.5g of  $HCl$  but, only 7.3g of  $HCl$  is available.

Hence the product  $CO_2$  formed depends only on the amount of  $HCl$  which is in the least amount but not on the amount of  $CaCO_3$  which is an excess. The reactant available in less amount is called *limiting reagent* as it limits the amount of product formed.

therefore, we can write

73 g of  $HCl \rightarrow 44$  g of  $CO_2$

7.3 g of  $HCl$  - ?

$$\frac{7.3\text{g} \times 44\text{g}}{73\text{g}} = 4.4 \text{ g}$$

44 g of  $CO_2$  occupies 22.4 L volume at STP

4.4 g of  $CO_2$  occupies - ?

$$\frac{4.4\text{g} \times 22.4 \text{ litres}}{44\text{g}} = 2.24 \text{ litres}$$

44 g of  $CO_2$  contain  $6.022 \times 10^{23}$  molecules of  $CO_2$

4.4 g Contains - ?

$$\frac{4.4\text{g} \times 6.022 \times 10^{23}}{44 \text{ g}} = 6.022 \times 10^{22} \text{ molecules}$$



## Key words

*Reactants, products, exothermic reaction, endothermic reaction Physical and chemical changes Primary or skelton Equation unit forumula, Precipitation, Co-efficient, atomic mass, standard temperature and pressure (STP) molar mass, avagadro's number, gram molar volume.*



## What we have learnt

- A Chemical equation is the symbolic representation of a chemical change.
- A balanced chemical equation explains about reactants, products and their physical states during the reaction.
- A chemical equation should always be balanced according to the Law of conservation of mass.
- The chemical reaction in which heat is absorbed are called endothermic reactions and in which heat is evolved are exothermic reactions.
- A chemical equation containing simply symbols of elements and molecular formulae of the substances without balancing is known as primary or skeleton equation.
- The symbols of elements and formulae of the compounds should not be changed but only their co-efficient should be altered while balancing the chemical equation.
- Co-efficient should be least possible whole numbers.



## Improve your learning

### I. Reflections on concepts

1. What information do you get from a balanced chemical equation? (AS<sub>1</sub>)
2. Why should we balance a chemical equation? (AS<sub>1</sub>)
3. Balance the following chemical equations. (AS<sub>1</sub>)
  - (a)  $\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$
  - (b)  $\text{KClO}_3 \rightarrow \text{KCl} + \text{O}_2$
  - (c)  $\text{Hg}(\text{NO}_3)_2 + \text{KI} \rightarrow \text{HgI}_2 + \text{KNO}_3$
4. Mention the physical states of the reactants and products of the following chemical reactions and balance the equatins. (AS<sub>1</sub>)
  - (a)  $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{CO}_2$
  - (b)  $\text{NH}_3 + \text{Cl}_2 \rightarrow \text{N}_2 + \text{NH}_4\text{Cl}$
  - (c)  $\text{Na} + \text{H}_2\text{O} \rightarrow \text{NaOH} + \text{H}_2$



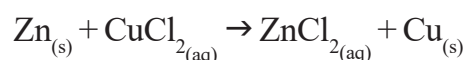
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## II. Application of Concepts

1. Balance the following chemical equation after writing the symbolic representation. (AS<sub>1</sub>)
  - (a) Calcium hydroxide (s) + Nitric acid (aq) → Water (l) + Calcium Nitrate (aq)
  - (b) Magnesium (s) + Iodine (s) → Magnesium Iodide (s)
2. Write the following chemical reactions including the physical states of the substances and balance chemical equations. (AS<sub>1</sub>)
  - (a) Sodium Hydroxide reacts with Hydrochloric acid to form Sodium Chloride and Water.
  - (b) Barium Chloride reacts with liquid Sodium Sulphate to leave Barium Sulphate as a precipitate and also form liquid Sodium Chloride.

## III. Higher Order Thinking Questions

1. 2 moles of Zinc reacts with a cupric chloride solution containing  $6.023 \times 10^{22}$  formula units of  $\text{CuCl}_2$ . Calculate the moles of copper obtained (AS<sub>1</sub>)



2. 1 mole of propane ( $\text{C}_3\text{H}_8$ ) on combustion at STP gives 'A' kilo joules of heat energy. Calculate the heat liberated when 2.4 ltrs of propane on combustion at STP. (AS<sub>1</sub>)
3. Calculate the mass and volume of oxygen required at STP to convert 2.4 kg of graphite into carbon dioxide. (AS<sub>1</sub>)

## Chapter

# 3



# Acids, Bases and Salts

In class VII you learnt about acids, bases and salts.

You know that acids are sour to taste and turn blue litmus to red, bases are soapy to touch and turn red litmus to blue.

You noticed that the person suffering from a problem of acidity, takes antacid tonic or chewing tablets.

- What chemical reaction takes place ?

There are many natural materials like litmus, extract of red cabbage, turmeric solution and extracts of coloured petals of some flowers contain dye molecules which are weak acids or bases. These can be used as acid-base indicators to detect the nature of the solution for acidity or basicity. In addition to the above natural acid-base indicators, there are some synthetic indicators such as methyl orange and phenolphthalein that can be used to test for acids and bases.

In this chapter you study the reactions of acids and bases. How do acids neutralize bases? Many more interesting activities that we use and see in our day-to-day life are also studied.

### **(?) Do you know?**

Litmus solution is a dye extracted from lichen, a plant belonging to the division of Thallophyta and is used as indicator. In neutral solution litmus colour is purple. Coloured petals of some flowers such as Hydrangea, Petunia and Geranium are also used as indicators.

## Chemical properties of Acids and Bases

Response of various laboratory substances with indicators.

### Activity 1

Collect the following samples from the science laboratory; hydrochloric acid (HCl), sulphuric acid (H<sub>2</sub>SO<sub>4</sub>), nitric acid (HNO<sub>3</sub>), acetic acid (CH<sub>3</sub>COOH), sodium hydroxide (NaOH), calcium hydroxide [Ca(OH)<sub>2</sub>], magnesium hydroxide [Mg(OH)<sub>2</sub>], ammonium hydroxide (NH<sub>4</sub>OH) and potassium hydroxide (KOH), prepare dilute solutions of the respective substances.

Take four watch glasses and put one drop of the first solution in each one of them and test the solution as follows.

- dip the blue litmus paper in the first watch glass.
- dip the red litmus paper in the second watch glass.
- add a drop of methyl orange to the third watch glass, and
- add a drop of phenolphthalein to the fourth watch glass.

Observe the respective colour changes and note down in Table-1. Do the same with all the above dilute solutions.

**Table-1**

S.No.	Sample solution	Red litmus paper	Blue litmus paper	Phenolphthalein solution	Methyl orange solution
1	HCl				
2	H <sub>2</sub> SO <sub>4</sub>				
3	HNO <sub>3</sub>				
4	CH <sub>3</sub> COOH				
5	NaOH				
6	KOH				
7	Mg(OH) <sub>2</sub>				
8	NH <sub>4</sub> OH				
9	Ca(OH) <sub>2</sub>				

- What do you conclude from the observations noted in table-1?
- Identify the sample as acidic or basic solution.

There are some substances whose odour changes in acidic or basic media. These are called olfactory indicators.

Let us work with some of such indicators.

## Activity 2

- Put some finely chopped onions in a plastic bag along with some clean cloth. Tie up the bag tightly and keep it overnight in the fridge. The cloth strips can now be used to test for acid or base.
- Check the odour of the cloth strips.
- Keep two strips on a clean surface and put a few drops of dilute HCl on one strip and a few drops of dilute NaOH on the other.
- Rinse both the strips separately with distilled water and again check their odour and note the observation.
- Take some clove oil and vanilla essence.
- Take some dilute HCl in one test tube and dilute NaOH in another test tube. Add a drop of dilute vanilla essence to both test tubes and stir well with glass rod. Check the odour and record your observations.
- Test the change of odour with clove oil using dilute HCl and dilute NaOH and record your observations.

Suggest which of these- onion, vanilla essence and clove oil, can be used as olfactory indicators on the basis of your observations.

- What do you conclude from above activity?



### Think and discuss

- Can you give example for use of olfactory indicators in daily life? Discuss with your teacher.

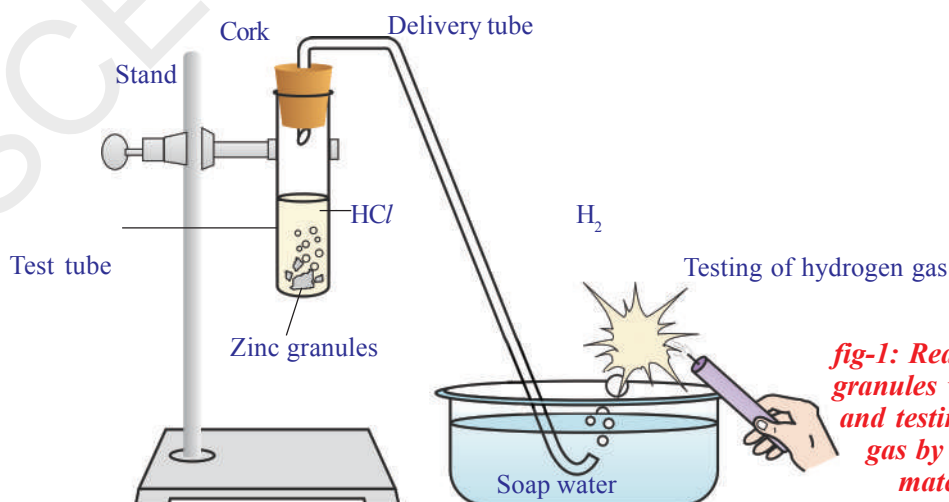
## Why pickles and sour substances are not stored in brass and copper vessels?

## Reaction of Acids and Bases with Metals



### Lab Activity

**Aim:** To observe the reaction of Acids with Metals.



*fig-1: Reaction of zinc granules with dil. HCl and testing hydrogen gas by a burning match stick*

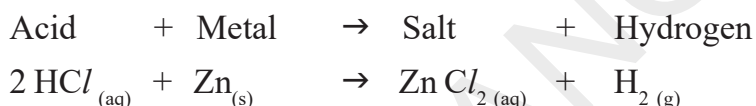
**Materials required:** test tube, delivery tube, glass trough, candle, soap water, dil. HCl, and zinc granules, cork.

**Procedure:** Set the apparatus as shown in fig. 1.

- Take about 10ml of dilute HCl in a test tube and add a few zinc granules to it.
- What do you observe on the surface of the zinc granules?
- Pass the gas being evolved through the soap water.
- Why are bubbles formed in the soap solution?
- Bring a burning candle near the gas filled bubble.
- What do you observe?

You will notice the gas evolved burns with a pop sound indicating H<sub>2</sub>.

The chemical reaction of the above activity is:



Repeat the above experiment with some other acids like H<sub>2</sub>SO<sub>4</sub> and HNO<sub>3</sub>.

- What do you observe in all these cases?

From the above activities you can conclude that generally H<sub>2</sub> gas is evolved when acid reacts with metal.

### Activity 3

Place a few granules of zinc metal in one of the test tubes and add 10 ml of sodium hydroxide (NaOH) solution and warm the contents of the test tube.

Repeat the rest of the steps as in activity-2 and record your observations.

In this activity also you will notice that evolved gas is hydrogen (H<sub>2</sub>) and salt formed is sodium zincate.

The reaction is written as follows.



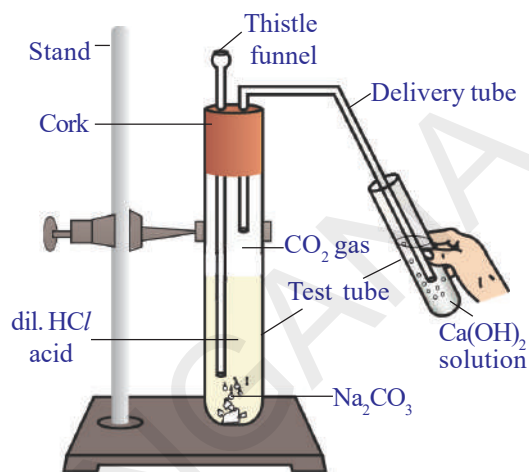
From the above activity you can conclude that generally H<sub>2</sub> gas is evolved when Acid reacts with metal.



## Reaction of acids with carbonates and metal hydrogen carbonates

### Activity 4

- Take two test tubes; label them as A and B. Take about 0.5 gm of sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) in test tube A and about 0.5 gm of sodium hydrogen carbonate ( $\text{NaHCO}_3$ ) in test tube B.
- Add about 2 ml of dilute  $\text{HCl}$  to both the test tubes.
- What do you observe?
- Pass the gas produced in each case through lime water (calcium hydroxide solution) as shown in Fig-2 and record your observations.



*fig-2: Passing  $\text{CO}_2$  gas through  $\text{Ca(OH)}_2$  solution*

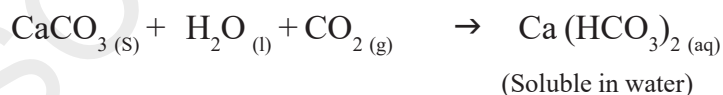
The reactions occurring in the above activities are as follows:



Pass the gas evolved through lime water.



On passing excess carbon dioxide the following reaction takes place:



Thus from above activities you can conclude that the reaction of metal carbonates and hydrogen carbonates with acids give a corresponding salt, carbon dioxide and water. We can write generalized form of these chemical reactions as shown below:



## Neutralization reaction

### Activity 5

#### Acid – base (Neutralization) reaction

Take about 2 ml of dilute NaOH solution in a test tube and add one drop of phenolphthalein indicator. Observe the colour of the solution.

- Add dilute HCl solution to the above solution drop by drop. Is there any change of colour of the solution?
- Why did the colour of the solution change after adding the HCl solution?
  - Now add one or two drops of NaOH to the above mixture.
- Does the Pink colour reappear?
- Do you guess the reason for reappearance of pink colour?

In the above activity you observe that the pink colour disappears on adding HCl because NaOH is completely reacted with HCl. The effect of base is nullified by an acid. Pink colour reappears on adding a drop of NaOH because the solution becomes basic once again. The reaction occurring between acid and base in the above activity can be written as:



The reaction of an acid with a base to give a salt and water is known as a neutralization reaction. In general, a neutralization reaction can be written as:



#### Think and discuss

- Is the substance present in antacid tablet acidic or basic?
- What type of reaction takes place in stomach when an antacid tablet is consumed?

## Reaction of Acids with metal oxides

### Activity 6

- Take a small amount of copper oxide (CuO) in a beaker and slowly add dilute hydrochloric acid while stirring. Observe the changes in the solution.
- Note the colour of the solution.

- What do you observe in the above reaction?

You will notice that the copper oxide present in the beaker dissolves in dilute HCl and the colour of the solution becomes blueish-green. The reason for this change is the formation of copper (II) chloride in the reaction. The general reaction between a metal oxide and an acid can be written as:



Write the chemical equation for the reaction between copper oxide and HCl and balance it.

In above reaction metal oxide reacts with acid to give salt and water. This reaction is similar to the reaction of a base with an acid that we have observed in activity - 5.

- What do you conclude from the Activity-5 and 6?

In both the reactions salt and water are the products. Both metallic oxides and metallic hydrides give salt and water when they react with an acid. Thus we can conclude that metal oxides are basic in nature like the metal hydroxides.

### Reaction of base with non-metal oxide

You saw the reaction between carbon dioxide and calcium hydroxide (lime water) in activity-4. Calcium hydroxide, which is a base, reacts with carbon dioxide to produce a salt and water. This reaction is similar to the reaction between a base and an acid. Thus we can conclude that carbon dioxide which is a non metal oxide is acidic in nature. In general all non-metal oxides are acidic in nature.



### Think and discuss

- You are provided with three test tubes containing distilled water, an acid and a base solution respectively. If you are given only blue litmus paper, how do you identify the contents of each test tube?
- A compound of Calcium reacts with dilute hydrochloric acid to produce effervescence. The gas evolved extinguishes a burning candle; turns lime water milky. Write a balanced chemical equation for the reaction if one of the compounds formed is calcium chloride.

### What do acids have in common?

In previous sections you have seen that acids have similar chemical properties. In lab activity you have observed that acids generate hydrogen gas on reacting with metals, so hydrogen seems to be common element to

all acids. Let us perform an activity to investigate whether all compounds containing hydrogen are acids or not.

### Activity 7

Prepare solutions of glucose, alcohol, hydrochloric acid and sulphuric acid etc.,

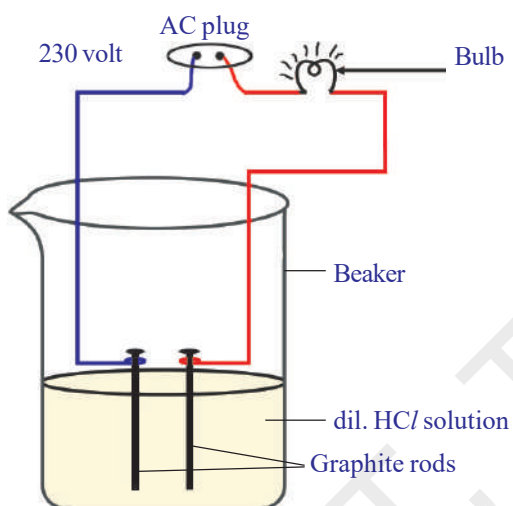
Connect two different coloured electrical wires to graphite rods separately in a 100 ml beaker as shown in figure.

Connect free ends of the wire to 230 volts AC plug and complete the circuit as shown in the fig-3 by connecting a bulb to one of the wires.

Now pour some dilute HCl in the beaker and switch on the current.

- What do you notice?

Repeat activity with dilute sulphuric acid and glucose and alcohol solutions separately.



**fig-3: Acid solution in water conducts electricity**

- What do you observe?
- Does the bulb glow in all cases?

You will notice that the bulb glows only in acid solutions but not in glucose and alcohol solutions. Glowing of bulb indicates that there is flow of electric current through the solution. Acid solutions have ions and the movement of these ions in solution helps for flow of electric current through the solution.

The positive ion (cation) present in HCl solution is  $H^+$ . This suggests that acids produce hydrogen ions  $H^+$  in solution, which are responsible for their acidic properties. In glucose and alcohol solution the bulb did not

glow indicating the absence of ( $H^+$ ) hydrogen ions in these solutions. The acidity of acids is attributed to the ( $H^+$ ) hydrogen ions produced by them in solutions.

### Properties of Bases

Repeat the Activity-7 using alkalis such as sodium hydroxide, calcium hydroxide solutions etc., instead of acid solutions.

- Does the bulb glow?
- What do you conclude from the results of this activity?

In electrolysis bulb glows as bases give hydroxide ( $OH^-$ ) a negative ion (Anion)

## Do acids produce ions only in aqueous solution? Let us test this.

### Activity 8

- Take about 1.0g of solid  $\text{NaCl}$  in a clean and dry test tube.
- Add some concentrated sulphuric acid to the test tube.
- What do you observe? Is there a gas coming out of the delivery tube?  
Let us write chemical equation for the above reaction.



Test the gas evolved successively with dry and wet blue litmus paper. In which case does the litmus paper change colour?

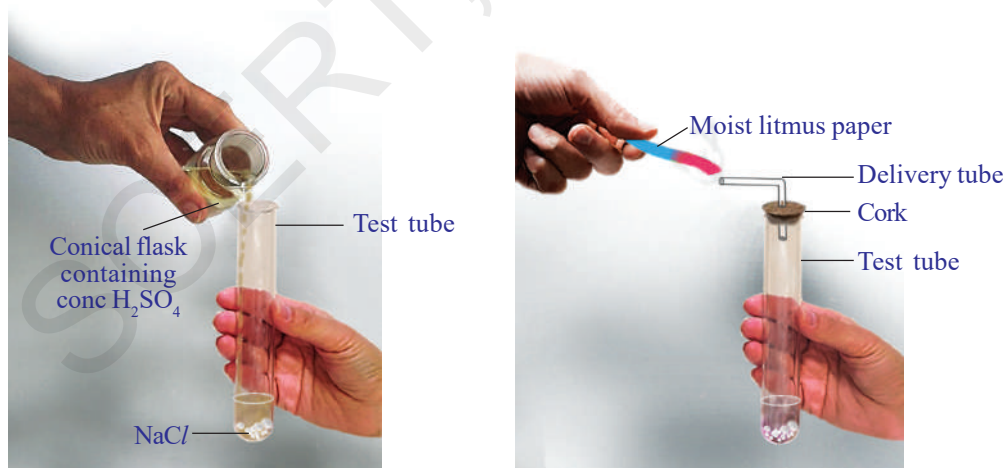
- What do you infer from the above observation?

You can conclude that dry  $\text{HCl}$  gas (Hydrogen chloride) is not an acid because you have noticed that there is no change in colour of dry litmus paper but  $\text{HCl}$  aqueous solution is an acid because wet blue litmus paper turned into red.

**Note to teachers:** If the climate is very humid, pass the gas produced through a guard tube (drying tube) containing calcium chloride to dry the gas.

- Can you write the chemical equation for the reaction takes place at the mouth of delivery tube?

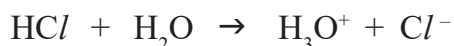
**Laboratory precautions :** Observe the following pictures. Did you find any problems with this? When ever you work with concentrated solutions it is very important to use test tube holder. It is very dangerous to work with bare hands in the laboratory.



*fig-4: Preparation of HCl gas*

The  $\text{HCl}$  gas evolved at delivery tube dissociates in presence of water to produce hydrogen ions. In the absence of water dissociation of  $\text{HCl}$  molecules do not occur.

The dissociation of  $\text{HCl}$  in water is shown below.

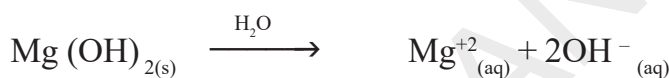
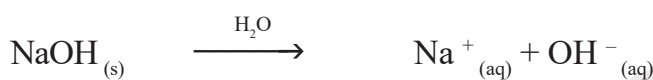


Hydrogen ions cannot exist as bare ions. They associate with water molecules and exist as hydrated ions with each  $\text{H}^+$  attached by 4 to 6 water molecules. For this we represent  $\text{H}^+$  as hydronium ion,  $\text{H}_3\text{O}^+$ .



You have learnt that acids give  $\text{H}_3\text{O}^+$  or  $\text{H}^+$  ion in water.

Let us see what happens when a base is dissolved in water.



On dissolving bases in water produces hydroxide ( $\text{OH}^-$ ) ions. Bases which are soluble in water are called alkalis. All bases do not dissolve in water.  $\text{Be}(\text{OH})_2$  is slightly soluble in water.

### What do you observe when water is mixed with acid or base?

#### Activity 9

- Take 10 ml water in a test tube.
- Add a few drops of concentrated  $\text{H}_2\text{SO}_4$  to it and swirl the test tube slowly.
- Touch the bottom of the test tube.
- What do you feel?

- Is it an exothermic or endothermic process?

Carry out the above activity with sodium hydroxide pellets instead of  $\text{H}_2\text{SO}_4$  and record your observation.

The process of dissolving an acid or a base in water is an exothermic process. Care must be taken while mixing concentrated nitric acid or sulphuric acid with water. The acid must always be added slowly to water with constant stirring. If water is added to a concentrated acid, the heat generated may cause the mixture to splash out and cause burns. The glass container may also break due to excessive local heating. Look out for the warning sign (shown in



*fig-5: Warning sign displayed on containers containing concentrated Acids and Bases*

Fig.5) on the can of concentrated sulphuric acid and on the bottle of sodium hydroxide pellets.

Mixing an acid or base with water result in decrease in the concentration of ions ( $\text{H}_3\text{O}^+/\text{OH}^-$ ) per unit volume. Such a process is called dilution and the acid or the base is said to be diluted.



### Think and discuss

- Why do  $\text{HCl}$ ,  $\text{HNO}_3$  etc., show acidic characters in aqueous solutions while solutions of compounds like alcohol and glucose do not show acidic character?
- While diluting an acid, why is it recommended that the acid should be added to water and not water to the acid?

Can you decide the strength of an acid or base solutions?

Let us find.

### Strength of acid or base:

#### Activity 10

A test to know whether the Acid is strong or weak.

- Take two beakers A and B.
- Fill the beaker A with dil.  $\text{CH}_3\text{COOH}$  (acetic acid) and beaker B with dil.  $\text{HCl}$  (Hydrochloric Acid)
- Arrange the apparatus as used in activity-7, and pass electric current through the solutions in separate beakers.
- What do you observe?
- Can you guess the reason for the changes you observed?

You notice that the bulb glows brightly in  $\text{HCl}$  solution while the intensity of the bulb is low in acetic acid solution. This indicates that there are more ions in  $\text{HCl}$  solution and fewer ions are present in acetic acid solution. More ions in  $\text{HCl}$  solution mean more  $\text{H}_3\text{O}^+$  ions. Therefore it is a strong acid. Whereas acetic acid has fewer  $\text{H}_3\text{O}^+$  ions and hence it is weak acid.

Carry out the above experiment by taking bases like dil.  $\text{NaOH}$  (sodium hydroxide) and dil.  $\text{NH}_4\text{OH}$  (ammonium hydroxide) instead of acids.

- What do you observe? Explain your observations.

The universal indicator can also be used to know the strength of acid or base. Universal indicator is a mixture of several indicators. The universal indicator shows different colours at different concentrations of hydrogen ions in a solution.

## pH scale

A scale for measuring hydrogen ion concentration in a solution is called pH scale. (The 'p' in pH stands for 'Potenz'. In German Language 'Potenz' is power). pH value of a solution is simply a number which indicates the acidic or basic nature of a solution.

The pH of neutral solutions is 7. Values less than 7 on the pH scale represent an acidic solution. As the pH value increases from 7 to 14, it represents a decrease in  $\text{H}_3\text{O}^+$  ion concentration or an increase in  $\text{OH}^-$  ion concentration in the solution. pH value of a solution above '7' represents a basic solution.

Observe the following figure.

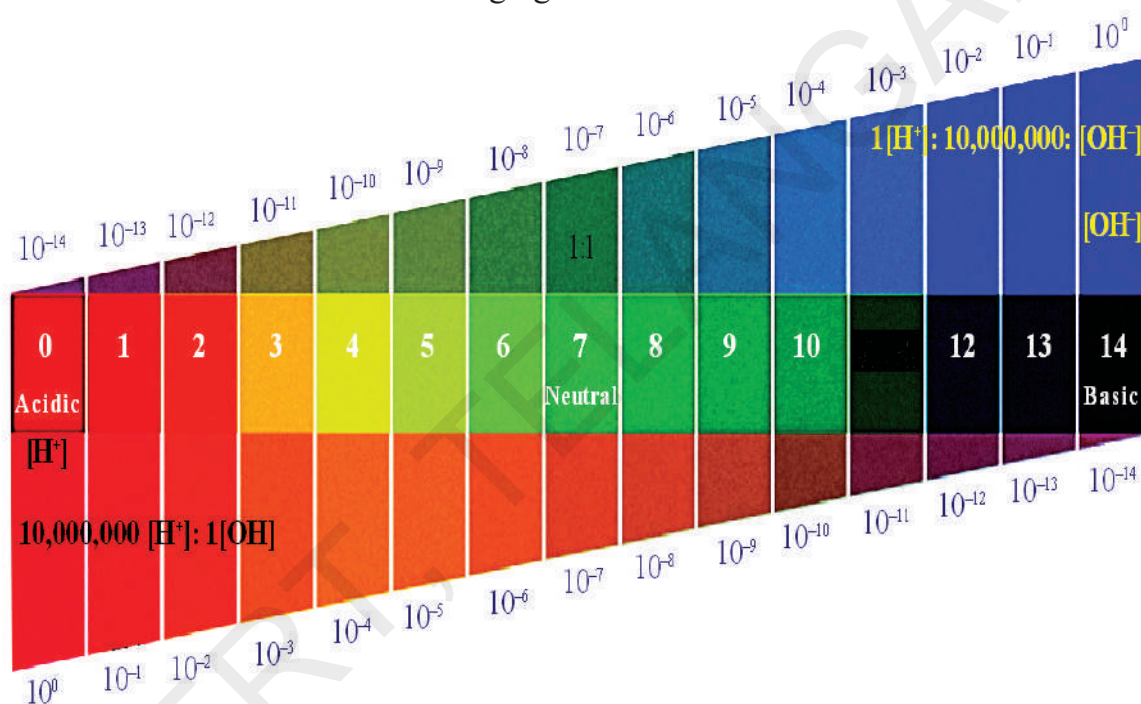


fig. - 6

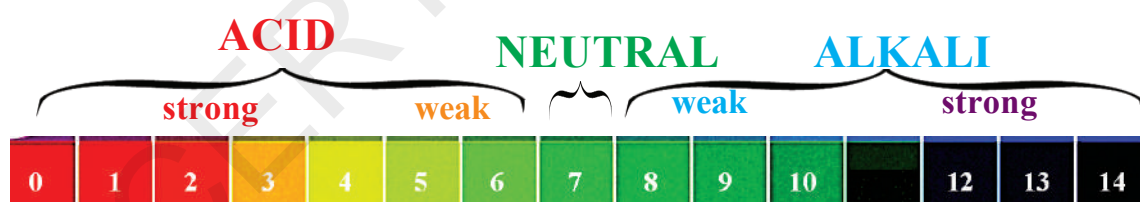
### Activity 11

- Test the pH value of solutions given in table using pH paper.
- Record your observations in column three of Table – 2.
- Write approximate pH values in column 4 using Universal Indicator solution.
- What is the nature of each substance on the basis of your observations?



**Table-2**

S.No.	Solution	Colour pH paper	Approximate pH value	Nature of substances
1	HCl			
2	CH <sub>3</sub> COOH			
3	NH <sub>4</sub> Cl			
4	CH <sub>3</sub> COONa			
5	NaHCO <sub>3</sub>			
6	Na <sub>2</sub> CO <sub>3</sub>			
7	NaOH			
8	Distilled water			
9	Lemon juice			
10	Carrot juice			
11	Coffee			
12	Tomato juice			
13	Tap water			
14	Banana juice			
15	Colourless aerated drink			
16	Saliva (before meal)			
17	Saliva (after meal)			



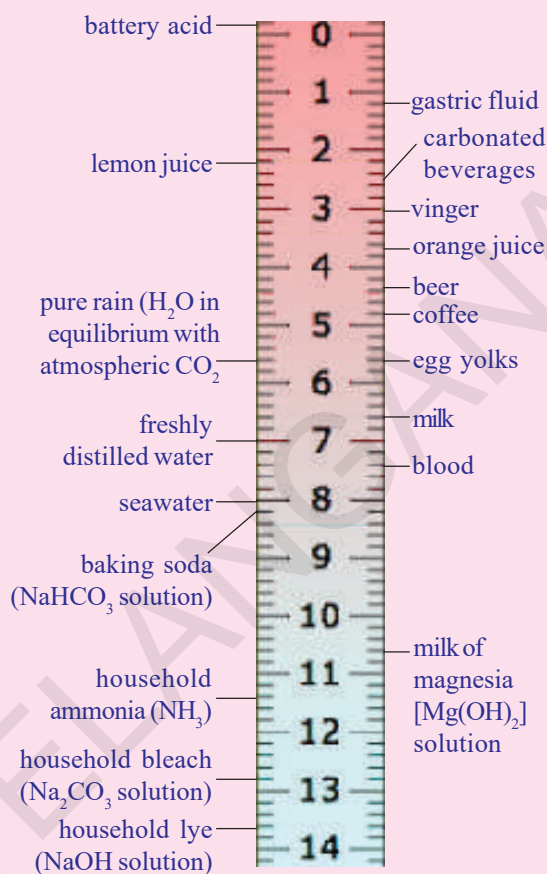
*fig -7: pH value as shown by different colour in universal indicator*

The strength of acid or base depends on the concentration of H<sub>3</sub>O<sup>+</sup> ions or OH<sup>-</sup> produced in solution. If we take hydrochloric acid and acetic acid of the same concentration then they produce different concentration of hydrogen ions. Acids that give more H<sub>3</sub>O<sup>+</sup> ions are said to be strong acids that give fewer H<sub>3</sub>O<sup>+</sup> ions are said to be weak acid. Can you now predict what weak and strong bases are?

## **(?) Do you know?**

To avoid the negative powers of  $H^+$  concentration in dilute acid and base solutions Sorensen introduced the concept of pH. Due to this pH concept may be restricted for solutions of  $[H^+]$  less than 1 molar.

The pH scale is from 0-14. The pH is an indication of concentration of  $H^+$ . For example, at a pH of zero the hydronium ion concentration is one molar. Typically the concentrations of  $H^+$  in water in most solutions fall between a range of 1 M (pH=0) and  $10^{-14}$  M (pH=14). Figure 8 depicts the pH scale with common solutions.



**fig -8: Solutions and the placement of them on pH scale**

## **Importance of pH in everyday life**

### **1. Are plants and animals pH sensitive?**

Living organisms can survive only in a narrow range of pH change. When pH of rain water is less than 5.6, it is called acid rain. When acid rain flows in to the rivers, it lowers the pH of the river water, the survival of aquatic life in such rivers becomes difficult.



### **Think and discuss**

- What will happen if the pH value in our body increases?
- Why do living organism have narrow pH range?

## 2. Is pH change cause of tooth decay?

Tooth decay starts when the pH of the mouth is lower than 5.5. Tooth enamel, made of calcium phosphate is the hardest substance in the body. It does not dissolve in water, but is corroded when the pH in the mouth is below 5.5. Bacteria present in the mouth produce acids by degradation of sugar and food particles remaining in the mouth. The best way to prevent this is to clean the mouth after eating food. Using tooth pastes, which are generally basic neutralize the excess acid and prevent tooth decay.

## 3. pH in our digestive system:

It is very interesting to note that our stomach produces hydrochloric acid. It helps in the digestion of food without harming the stomach. During indigestion the stomach produces too much acid and this causes pain and irritation. To get rid of this pain, people use bases called antacids. These antacids neutralize the excess acid in the stomach. Magnesium hydroxide (milk of magnesia), a mild base, is often used for this purpose.

### Activity 12

- Take dil. HCl in a beaker and add two to three drops methyl orange indicator. Note the colour of the solution
- Mix antacid tablet powder to the above solution in the beaker. Now observe the change in colour of solution.
- What is the reason for the change in colour of solution?
- Can you write the chemical equation for this reaction?

## 4. pH of the soil

Plants require a specific pH range for their healthy growth. To find out the pH required for the healthy growth of a plant, you can collect the soil samples from various places and check the pH in the manner described below in the following activity. Also you can note down what type of plants are growing in the region from which you have collected the soil.

### Activity 13

Put about 2g soil in a test tube and add 5ml water to it. Shake the contents of the test tube. Filter the contents and collect the filtrate in a test tube.

Check the pH of this filtrate with the help of universal indicator paper.



### Think and discuss

- What can you conclude about the ideal soil pH for the growth of plants in your region?
- Under what soil conditions a farmer would treat the soil of his fields with quicklime or calcium carbonate?

## Self defense by animals and plants through chemical warfare?

Have you ever been stung by a honey-bee? Bee sting leaves an acid which causes pain and irritation. Use of a mild base like baking soda on the stung area gives relief. Stinging hair of leaves of nettle plant, inject methanoic acid (formic acid) causing burning pain.

A traditional remedy is rubbing the area with the base natured leaf of the dock plant, which often grows besides the nettle in the wild.

## Salts

In the previous sections you have studied the formation of salts by the neutralization reaction of base with an acid. Let us understand more about the preparation, properties and uses of salts.

### Family of salts

#### Activity 14

- Write the formulae of the following salts.
- Potassium sulphate, sodium sulphate, calcium sulphate, magnesium sulphate, copper sulphate, sodium chloride, sodium nitrate, sodium carbonate and ammonium chloride.
- Identify the acids and bases from which the above salts are obtained.
- Salts having the same positive or negative radicals belong to a family. For example,  $\text{NaCl}$  and  $\text{Na}_2\text{SO}_4$  belong to the family of sodium salts. Similarly,  $\text{NaCl}$ , and  $\text{KCl}$  belong to the family of chloride salts.
- How many families can you identify among the salts given above?

### pH of Salts

#### Activity 15

- Collect the salt samples like, sodium chloride, aluminum chloride, copper sulphate, sodium acetate, ammonium chloride, sodium hydrogen carbonate and sodium carbonate.
- Dissolve them in distilled water.
- Check the action of these solutions with litmus papers.
- Find the pH using pH paper (universal indicator).
- Classify them into acidic, basic or neutral salts?
- Identify the acid and base used to form the above salts.
- Record your observations in Table-3 given below.

**Table - 3**

Salt	pH	Acidic	Basic	Neutral

Salts of a strong acid and a strong base are neutral and the pH value is 7. The salts of a strong acid and weak base are acidic and the pH value is less than 7. The salts of a strong base and weak acid are basic in nature and the pH value is more than 7.

- What do you say about salts of both weak acid and weak base?

In such cases the pH depends on the relative strengths of acid and base.

### **Chemicals from common salt**

Salts are the ionic compounds which are produced by the neutralization of acid with base. Salts are electrically neutral. There are number of salts but sodium chloride is the most common among them. Sodium chloride is also known as table salt or common salt. Sodium chloride is used to enhance the taste of food.

Sea water contains many salts dissolved in it. Sodium chloride is the predominant component and it is separated from these salts. Deposits of solid salt are also found in several parts of the world. These deposits of large crystals are often brown due to impurities. This is called rock salt. Beds of rock salt were formed when seas of bygone ages dried up. Rock salt is mined like coal.

### **Common salt – A raw material for chemicals**

The common salt is an important raw material for various materials of daily use, such as sodium hydroxide, baking soda, washing soda, bleaching powder and many more. Let us see how one substance is used for making all these different substances.

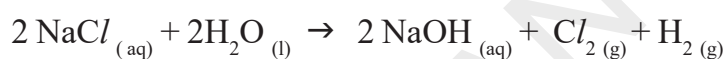
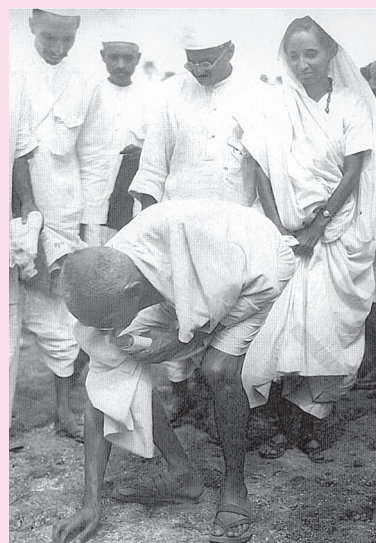
### **Sodium hydroxide from common salt**

When electricity is passed through an aqueous solution of sodium chloride (called brine), it decomposes to form sodium hydroxide. The process is called the chloro-alkali process – because of the products formed chloro for chlorine and alkali for sodium hydroxide.

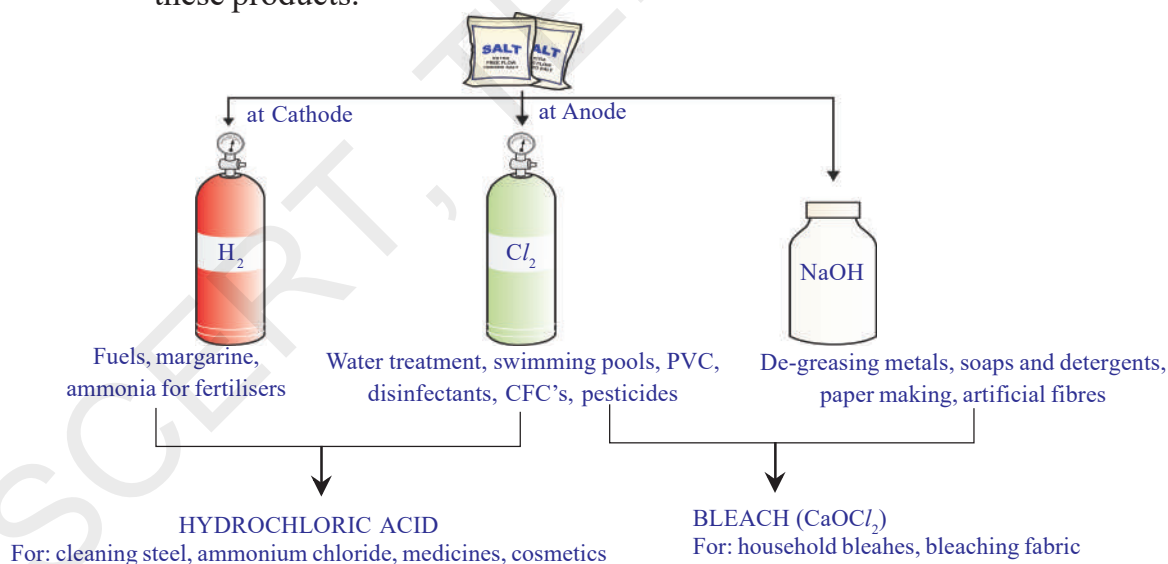
## **(?) Do you know?**

**Salt – a symbol of freedom struggle:** You know common salt as a substance which enhances the taste of food; it also has played a remarkable role in motivating the people towards freedom struggle. The tax levied by the British government on common food substance (salt), for both the poor and the rich, made them to become unite in the freedom struggle.

You must have heard about Mahatma Gandhi's Dandi March and about 'salt satyagraha' in the struggle for freedom of India.



Chlorine gas is given off at the anode and hydrogen gas at the cathode, sodium hydroxide solution is formed near the cathode the three products produced in this process are all useful Fig.-9 shows the different uses of these products.

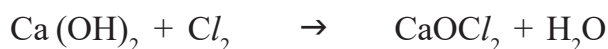


**fig-9: Important product from chloro-alkali process**

## **Bleaching Powder**

You know that chlorine is produced during the electrolysis of aqueous sodium chloride (brine). This chlorine gas is used for the manufacture of bleaching powder. Bleaching powder is produced by the action of chlorine

on dry slaked lime  $[\text{Ca}(\text{OH})_2]$ . Bleaching powder is represented by formula  $\text{CaOCl}_2$ , though the actual composition is quite complex.

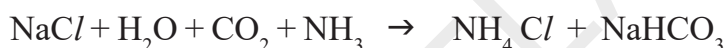


### Uses of Bleaching Powder:

1. It is used for bleaching cotton and linen in the textile industry for bleaching wood pulp in paper industry and for bleaching washed clothes in laundry.
2. Used as an oxidizing agent in many chemical industries.
3. Used for disinfecting drinking water to make it free of germs.
4. Used as a reagent in the preparation of chloroform.

### Baking soda

Baking soda is sometimes added for faster cooking. The chemical name of the compound is sodium hydrogen carbonate ( $\text{NaHCO}_3$ ). It is prepared as follows:



Can you find the pH of sodium hydrogen carbonate as you have done in activity-14? Can you predict the reason for using  $\text{NaHCO}_3$  to neutralize an acid?

Baking soda is a mild non-corrosive base.

The following reaction takes place when it is heated during cooking.

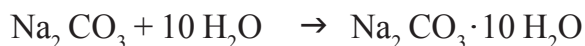


### Uses of sodium hydrogen carbonate

- i) Baking powder mainly contains  $\text{NaHCO}_3$  and its other components are  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  and starch.  $\text{NaHCO}_3$  produces  $\text{CO}_2$  which rises through bubbling dough into cake or bread. This results cake and bread are smooth and spongy.
- ii) Sodium hydrogen carbonate is also an ingredient in antacids. Being alkaline, it neutralizes excess acid in the stomach and provides relief.
- iii) It is also used as soda-acid in fire extinguishers
- iv) It acts as mild antiseptic.

## Washing soda (sodium carbonate)

Another chemical that can be obtained from sodium chloride is  $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$  (washing soda). You have seen above that sodium carbonate can be obtained by heating baking soda. Recrystallisation of sodium carbonate gives washing soda. It is also a basic salt.



Sodium carbonate and sodium hydrogen carbonate are useful chemicals for many industrial processes.

### Uses of Washing soda

- Sodium carbonate (washing soda) is used in glass, soap and paper industries.
- It is used in the manufacture of sodium compounds such as borax.
- Sodium carbonate can be used as a cleaning agent for domestic purposes.
- It is used for removing permanent hardness of water.

- What does  $10\text{H}_2\text{O}$  signify from the above equation?

Does it make  $\text{Na}_2\text{CO}_3$  wet?

Are the crystals of salts really dry?

Let us find

### Removing water of crystallisation

#### Activity 16

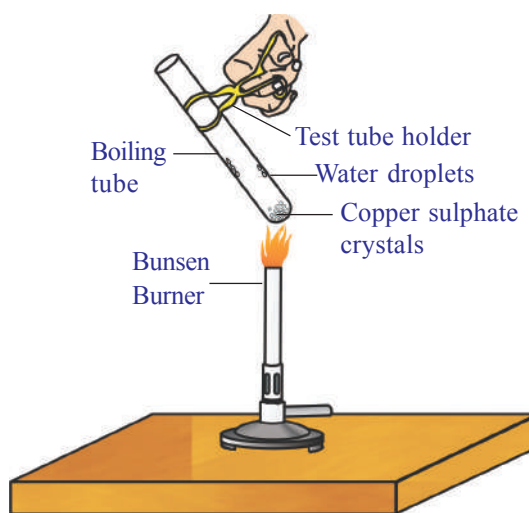
- Take a few crystals of copper sulphate in a dry test tube and heat the test tube.

- What change did you notice in the colour of the copper sulphate after heating?

- Did you notice water droplets on sides of the test tube? Where did they come from?

Add 2-3 drops of water on the sample of copper sulphate obtained after heating.

- What do you observe? Is the blue colour of copper sulphate restored?



*fig-10: Removing water of crystallisation*



In the above activity copper sulphate crystals which seem to be dry contain the water of crystallization, when these crystals are heated, water present in crystals is evaporated and the salt turns white.

When the crystals are moistened with water, the blue colour reappears.

Water of crystallization is the fixed number of water molecules present in one formula unit of a salt. Five water molecules are present in one formula unit of copper sulphate. Chemical formula for hydrated copper sulphate is  $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ .

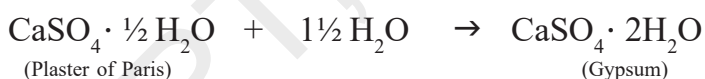
Now you would be able to answer the question whether the molecule of  $\text{Na}_2 \text{CO}_3 \cdot 10 \text{H}_2\text{O}$  is wet or not.

Another salt which possesses water of crystallisation is gypsum. It has two water molecules in its crystals and the formula is  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ .

Let us see the use of this salt.

### Plaster of paris ( $\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O}$ )

On careful heating of gypsum ( $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$ ) at 373 K it loses water molecules partially to become calcium sulphate hemihydrate ( $\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O}$ ). This is called *plaster of paris*, the substance which doctors use as plaster for supporting fractured bones in the right position. Plaster of paris is a white powder and on mixing with water, it sets into hard solid mass due to the formation of gypsum.



**Note:** You might have noticed that only half a water molecule is shown to be attached as water of crystallisation.

- How can you get half a water molecule?

It is written in this form because two formula units of  $\text{CaSO}_4$  share one molecule of water.

Plaster of paris is used for making toys, materials for decoration and for making surfaces smooth.



## Key words

*Indicator, Acid, Base, Red litmus, Blue litmus, Phenolphthalein, Methyl orange, Salts, Neutralization, Guard tube, Hydronium ion, Alkali, Strong acid, Strong base, Universal indicator, pH scale, Potenz, Antacids, tooth decay, Family of Salts, Common salt, Bleaching powder, Baking soda, Washing soda, Hydrated salt, Water of crystallization, Plaster of Paris.*



## What we have learnt

- Acid – base indicators are dyes or mixtures of dyes which are used to detect the presence of acids and bases.
- Acidic nature of a substance is due to the formation of  $H^+$  (aq) ions in solution. Formation of  $OH^-$  (aq) ions in solution is responsible for the basic nature of a substance.
- When a base reacts with a metal with the evolution of hydrogen gas, a salt is formed.
- When an acid reacts with a metal carbonate or metal hydrogen carbonate gives the corresponding salt, carbon dioxide gas and water.
- Acidic and basic solutions in water conduct electricity because they produce hydrogen ions and hydroxide ions respectively.
- The strength of an acid or an alkali can be tested by using a scale called the pH scale (0-14) which gives the measure of hydrogen ion concentration in a solution.
- A neutral solution has a pH of 7, while an acidic solution has a pH less than 7 and a basic solution has a pH more than 7.
- Living beings carry out their metabolic activities within an optimal pH range.
- Mixing concentrated acids or bases with water is a highly exothermic process.
- Acids and bases neutralize each other to form corresponding salts and water.
- Water of crystallization is the fixed number of water molecules chemically attached to each formula unit of a salt in its crystalline form.
- Salts have various uses in everyday life and in industries.



## Improve your learning



### Reflections on concepts

1. An acid or a base is mixed with water. Is this process exothermic or endothermic one? (AS<sub>1</sub>)
2. Distilled water does not conduct electricity. Why? (AS<sub>1</sub>)

3. Draw a neat diagram for showing acid solution in water conducting electricity. (AS<sub>5</sub>)
4. Why the flow of acid rain into a river make the survival of aquatic life in a river difficult? (AS<sub>7</sub>)
5. How does baking powder make the cake soft and spongy? (AS<sub>7</sub>)

### Application of concepts

1. Five solutions A, B, C, D and E when tested with universal indicator showed pH as 4, 1, 11, 7 and 9, respectively, classify the solutions as given below.(AS<sub>1</sub>)  
(a) neutral (b) strongly alkaline (c) strongly acidic (d) weakly acidic (e) weakly alkaline
2. Why does tooth decay start when the pH of mouth is lower than 5.5? (AS<sub>1</sub>)
3. A milkman adds a very small amount of baking soda to fresh milk. Write reasons for the following. (AS<sub>2</sub>)
  - a) Why does he shift the pH of the fresh milk from acidic nature to slightly alkaline?
  - b) Why does this milk take a long time to set as curd?
4. Plaster of Paris should be stored in moisture – proof container. Explain why? (AS<sub>1</sub>)
5. Magnesium ribbons of same size are taken in test tubes A and B. Hydrochloric acid is added to test tube A, while acetic acid is added to test tube B. The concentrations of both the acids are the same. In which test tube will the fizzing occur more vigorously ? why? (AS<sub>3</sub>)

### Higher Order Thinking Questions

1. Fresh milk has a pH of 6.6. Explain why the pH changes as it turns into curd? (AS<sub>3</sub>)
2. How do you prepare an indicator using beetroot? Explain. (AS<sub>5</sub>)

### Multiple choice questions

1. The colour of methyl orange indicator in acidic medium is [     ]  
A) Yellow                      B) green                      C) orange                      D) red
2. The colour of phenolphthalein indicator in basic solution is [     ]  
A) yellow                      B) green                      C) pink                      D) orange
3. Colour of methyl orange in alkali conditions? [     ]  
A) orange                      B) yellow                      C) red                      D) blue
4. A solution turns red litmus blue, its pH is likely to be [     ]  
A) 1                      B) 4                      C) 5                      D) 10
5. A solution reacts with crushed egg-shells to give a gas that turns lime-water milky. The solution is of [     ]  
A) NaCl                      B) HCl                      C) LiCl                      D) KCl

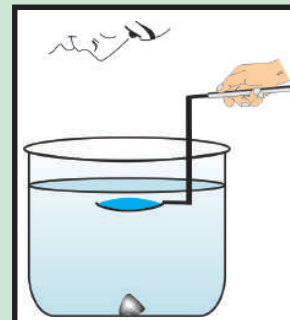
6. If a base dissolves in water by what name is it better known? [ ]  
A) neutral      B) base      C) acid      D) alkali
7. Which of the following substances when mixed together will produce table salt? [ ]  
A. Sodium thiosulphate and sulphur dioxide  
B. Hydrochloric acid and sodium hydroxide  
C. Chlorine and oxygen  
D. Nitric acid and sodium hydrogen carbonate
8. What colour would hydrochloric acid (pH=1) turn universal indicator? [ ]  
A) orange      B) purple      C) yellow      D) red
9. Which one of the following types of medicines is used for treating indigestion?[ ]  
A) antibiotic    B) analgesic    C) antacid    D) antiseptic
10. What gas is produced when magnesium is made to react with hydrochloric acid?[ ]  
A) hydrogen    B) oxygen    C) carbon dioxide    D) chlorine

### Suggested Experiments

1. Compounds such as alcohols and glucose contain hydrogen but are not categorized as acids. Describe an activity to prove it.
2. What is meant by “water of crystallization” of a substance? Describe an activity to show the water of crystallization.

### Suggested Projects

1. How do you Select a good place to plant a tree in your school / at home. Test the soil and investigate and write a report on it.
2. Do all vegetables are acids? To find this investigate with  $p^H$  paper and tabulate the values and write a report on it.
3. Collect information about importance of the  $p^H$  value in daily life to human beings as well as plants.
4. Try to collect the information for calling calcium sulphate hemihydrates as Plaster of Paris.



# Refraction of Light at Curved Surfaces

It is a common observation that some people use spectacles for reading. The watch repairer uses a small magnifying glass to see tiny parts of a watch.

- Have you ever touched a magnifying glass with your hand?
- Have you touched the glass in the spectacles used for reading with your hand?
- Is it a plane or curved surface?
- Is it thicker in the middle or at the edge?

We have learnt about refraction of light at a plane surface in the previous class. Now let us understand refraction of light at curved surfaces.

Let us do an activity to understand refraction of light at curved surfaces.

## Refraction of light at a curved surface

### Activity 1

Draw an arrow of length 4 cm using a black sketch pen on a thick sheet of paper. Take an empty cylindrical-shaped transparent vessel such as glass tumbler. Keep it on the table. Ask your friend to bring that sheet of paper on which arrow was drawn behind the vessel while you looking at it from the other side (The arrow mark should be in horizontal position).

- What do you see?  
You will see a diminished (small-sized) image of the arrow
- Why do you see a diminished image?
- Is the image real or virtual?
- Can you draw a ray diagram showing how it is formed?

Ask your friend to fill the vessel with water. Look at the fig.- of arrow from the same position as before.

- What do you see now?
- Do you get an inverted image?
- How could this happen?

In the first case, when the vessel is empty, light from the arrow refracts at the curved interface, moves through the glass and enters into air then it again undergoes refraction on the opposite curved surface of the vessel (at the other end from where we are looking) and comes out into the air. In this way light travels through two media and comes out of the vessel and forms a diminished image.

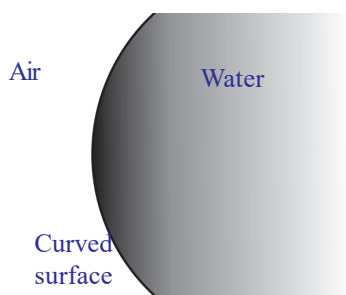


fig-1

In the second case, light enters through the curved surface, moves through water, comes out of the glass and forms an inverted image.

When the vessel is filled with water, there is a curved interface between two different media (air and water). Assume that the refractive indices of both water and glass are the same (they really are not equal). This setup of air and water separated by a curved surface is shown in fig.- 1.

- What happens to a ray that is incident on a curved surface separating the two media?
- Are the laws of refraction still valid?

Let us find out.

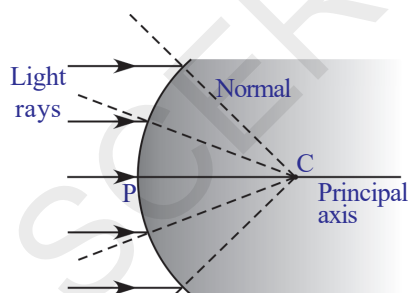


fig-2

Consider a curved surface separating two different media as shown in fig.- 2. The centre of the sphere, of which curved surface is a part, is called as the *centre of curvature*. It is denoted by letter 'C'.

Any line drawn from the centre of curvature to a point on the curved surface becomes normal to the curved surface at that point. The direction of the normal changes from one point to another point on the curved surface. The centre of the curved surface is called the *pole (P)* of the curved surface. The *line that joins the centre of curvature and the pole is called 'principal axis'*.

- How do rays bend when they are incident on a curved surface?

As in the case of plane surfaces, a ray will bend towards the normal if it travels from a rarer to denser medium and it bends away from the normal if it travels from a denser to a rarer medium .

Let us see how we can draw ray diagrams for certain useful cases.

- What happens to a ray that travels along the principal axis? Similarly, a ray that travels through the centre of curvature?

According to Snell's law the ray which travels along the normal drawn to the surface does not deviate from its path. Hence both rays mentioned above will travel along the normal (see fig.-3), so they do not deviate.

- What happens to a ray travelling parallel to the principal axis?

Observe the following figures 4(a), 4(b), 4(c), and 4(d). In all the cases as represented by the diagrams, the incident ray is parallel to the principal axis.

**Case1:** A ray travelling parallel to the principal axis strikes a convex surface and passes from a rarer medium to denser medium. (see fig.-4(a))

**Case2:** A ray travelling parallel to the principal axis strikes a convex surface and passes from a denser medium to rarer medium. (see fig.-4(b))

**Case3:** A ray travelling parallel to the principal axis strikes a concave surface and passes from a denser medium to rarer medium. (see fig-4(c))

**Case4:** A ray travelling parallel to the principal axis strikes a concave surface and passes from a rarer medium to denser medium. (see fig. 4(d))

- What difference do you notice in the refracted rays in figures 4(a) and 4(b)?

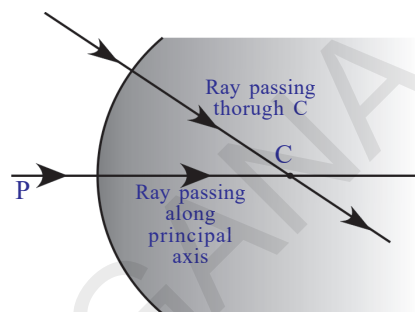


fig-3

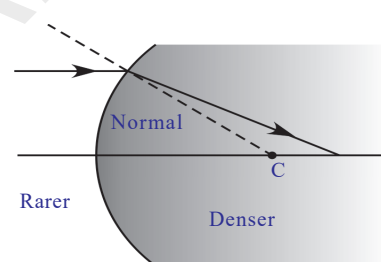


fig-4(a)

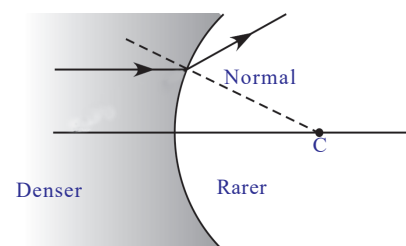


fig-4(b)

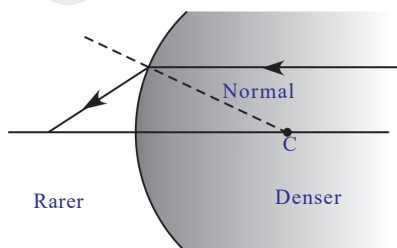


fig-4(c)

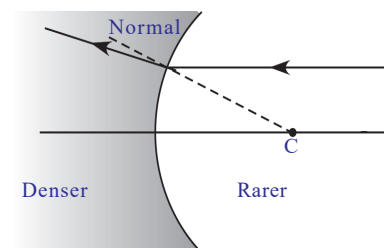


fig-4(d)

- What could be the reason for that difference?
- What difference do you notice in refracted rays in fig. - 4c and 4d?
- What could be the reasons for that difference?

You might have noticed that in figures 4(a) and 4(c) the refracted ray reaches a particular point on the principal axis. In figures 4(b) and 4(d) the refracted ray moves away from the principal axis. When you extend the refracted ray backwards along the ray as shown in 4b and 4d, the extended ray intersects the principal axis at some point. The point where refracted ray intersects the axis in all the above cases is called the *focal point*.

You might have observed that a lemon in a glass of water appears bigger than its actual size, when viewed from the sides of tumbler.

- How can you explain this change in the size of lemon?
- Is the lemon that appears bigger in size an image of lemon or is it the real lemon?
- Can you draw a ray diagram to explain this phenomenon?

Let us find out.

### Image formation

Consider a curved surface separating two media of refractive indices  $n_1$  and  $n_2$  ( fig.- 5). A point object is placed on the principal axis at point O. The ray, which travels along the principal axis passes through the pole undeviated. The second ray, which forms an angle  $\alpha$  with principal axis, meets the interface (surface) at A. The angle of incidence is  $\theta_1$ . The ray bends and passes through the second medium along the line AI. The angle of refraction is  $\theta_2$ . The two refracted rays meet at I and the image is formed there.

### Derivation of curved surface formula

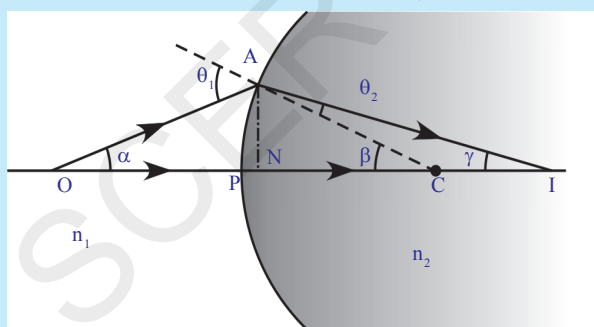


fig-5

Let the angle made by the second refracted ray with principal axis be  $\gamma$  and the angle between the normal and principal axis be  $\beta$ . (see fig.- 5)

In fig.- 5,

PO is the object distance which we denote as 'u'

PI is image distance which we denote as 'v'

PC is radius of curvature which we denote as 'R'

$n_1, n_2$  are refractive indices of two media.

Can you establish any relation between the above mentioned quantities?

In the triangle ACO,  $\theta_1 = \alpha + \beta$



and in the triangle ACI,  $\beta = \theta_2 + \gamma \Rightarrow \beta - \gamma = \theta_2$

According to Snell's law, we know

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

substituting the values of  $\theta_1$  and  $\theta_2$ , we get,

$$n_1 \sin(\alpha + \beta) = n_2 \sin(\beta - \gamma) \dots\dots\dots (1)$$

If the rays move very close to the principal axis, the rays can be treated as parallel and are called *paraxial rays*. Then the angles  $\alpha$ ,  $\beta$  and  $\gamma$  become very small. This approximation is called *paraxial approximation*.

$$\sin(\alpha + \beta) = \alpha + \beta \text{ and } \sin(\beta - \gamma) = \beta - \gamma$$

Substituting in equation (1)

$$n_1 (\alpha + \beta) = n_2 (\beta - \gamma) \Rightarrow n_1 \alpha + n_1 \beta = n_2 \beta - n_2 \gamma \dots\dots\dots(2)$$

since all angles are small, we can write

$$\tan \alpha = AN/NO = \alpha$$

$$\tan \beta = AN/NC = \beta$$

$$\tan \gamma = AN/NI = \gamma$$

Substitute these in equation (2), we get,

$$n_1 AN/NO + n_1 AN/NC = n_2 AN/NC - n_2 AN/NI \dots\dots\dots (3)$$

As the rays move very close to the principal axis, the point N coincides with pole of the interface (P). Therefore NI, NO, NC can be replaced by PI, PO and PC respectively.

After substituting these values in equation (3), we get,

$$n_1/PO + n_1/PC = n_2/PC - n_2/PI$$

$$n_1/PO + n_2/PI = (n_2 - n_1)/PC \dots\dots\dots(4)$$

Equation (4) shows the relation between refractive indices of two media, object distance, image distance and radius of curvature.

The above equation is true for the case we considered.

We can generalize equation (4) if we use the following sign convention.

For all purposes of applications of refraction at curved surfaces and through lenses following conventions are used.

- All distances are measured from the pole (or optic centre).
- Distances measured along the direction of the incident light ray are taken as positive
- Distances measured opposite to the direction of the incident light ray are taken as negative
- The heights measured vertically above from the points on axis are taken as positive
- The heights measured vertically down from points on axis are taken as negative.

Here PO is called the *object distance* ( $u$ )

PI is called the *image distance* ( $v$ )

PC is called *radius of curvature* ( $R$ )

According to sign convention mentioned above, we have

$$PO = -u ; PI = v ; PC = R$$

Substituting these values in equation (4) we get,

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R} \dots\dots\dots (5)$$

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$$

This formula can also be used for plane surfaces. In the case of a plane surface, radius of curvature ( $R$ ) approaches infinity. Hence  $1/R$  becomes zero. Substituting this in equation 5, we get formula for the plane surfaces

$$\frac{n_2}{v} - \frac{n_1}{u} = 0 \Rightarrow \frac{n_2}{v} = \frac{n_1}{u}$$

**NOTE:** The distances  $u$  and  $v$  are measured from the plane interface.

Let us consider the following examples.

**Example 1**

A bird is flying down vertically towards the surface of water in a pond with constant speed. There is a fish inside the water. If that fish is exactly vertically below the bird, then the bird will appear to the fish to be:

- a. farther away than its actual distance.
- b. closer than its actual distance.
- c. moving faster than its actual speed.
- d. moving slower than its actual speed.

Which of the four options are true? How can you prove it?

**Solution:** For refraction at a plane surface,

$$\text{we use } \frac{n_2}{v} = \frac{n_1}{u} \dots\dots\dots(1)$$

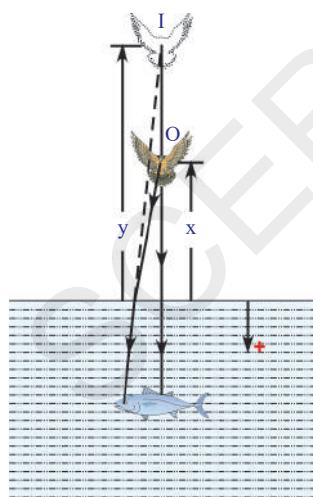
Let  $x$  be the height of the bird above the water surface at an instant and  $n$  be the refractive index of water.

$n_1$  = refractive index of air,

Then  $n_1 = 1, n_2 = n, u = -x$  and let  $v = -y$ , (see fig.- E1)

Substituting these values in equation (1)

$$\frac{n}{(-y)} = \frac{1}{(-x)} \Rightarrow y = nx$$



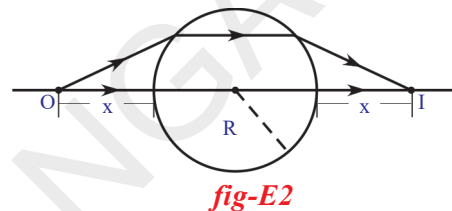
**fig-E1**

In the above equation, we know that  $n$  is greater than 1. Hence  $y$  is greater than  $x$ . Thus the bird appears to the fish to be farther away than its actual distance. We have assumed that bird is flying vertically down with constant speed. For the observer on the ground, bird appears that it has covered 'x' distance for certain time. But for fish, it appears that bird has covered a distance 'y' in the same time. As  $y$  is greater than  $x$ , we can conclude that the speed of the bird, observed by the fish, is greater than its actual speed.

So, options (a) and (c) are correct.

### Example 2

A transparent sphere of radius  $R$  and refractive index  $n$  is kept in air. At what distance from the surface of the sphere should a point object be placed on the principal axis so as to form a real image at the same distance from the second surface of the sphere?



**Solution:** From the symmetry of fig.- E2, the rays must pass through the sphere parallel to the principal axis.

From the figure,

$u = -x$ ,  $v = \infty$  (refracted ray is parallel to the optical axis after refraction at first surface)

$n_1 = 1$  and  $n_2 = n$ , (where  $n_1$  is refractive index of air)

$$\text{Using } \frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$$

$$\frac{n}{\infty} - \frac{1}{-x} = \frac{(n-1)}{R} \Rightarrow \frac{1}{x} = \frac{(n-1)}{R}$$

$$\Rightarrow x = \frac{R}{(n-1)}$$

Object distance from the first surface of the sphere is  $x = R/(n-1)$

### Example 3

A transparent (glass) sphere has a small, opaque dot at its centre. Does the apparent position of the dot appear to be the same as its actual position when observed from outside?

**Solution:** Let refractive index of glass  $n_1 = n$   
refractive index of air  $n_2 = 1$

Then  $u = -R$  (radius of sphere) ; Radius of curvature  $R = -R$

$$\text{Using } \frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$$

$$\frac{1}{v} - \frac{n}{(-R)} = \frac{(1-n)}{(-R)}$$

After solving this equation, we get

Image distance  $v = -R$

Thus we can say that the image distance and object distance are equal and that the apparent position of dot is the same as its actual position.

It is independent of the refractive index of the material of the sphere.

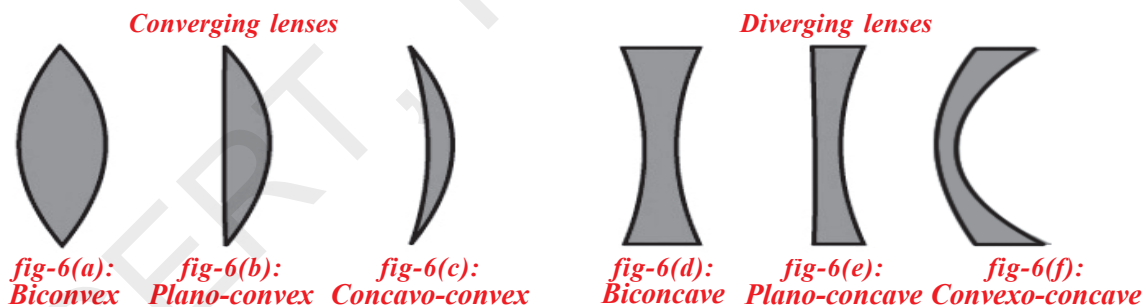
Till now we have discussed refraction of light at a single curved surface either convex or concave. Let us suppose that a transparent material has two curved surfaces.

- What happens to the light ray when a transparent material with two curved surfaces is placed in its path?
- Have you heard about lenses?
- How does a light ray behave when it is passed through a lens?

Let us learn about refraction of light through lenses.

### Lenses

A lens is formed when a transparent material is bounded by two surfaces of which one (or) both surfaces are spherical. That is a lens is bounded by atleast one curved surface. Lenses can be of various types. Some typical lenses along with their names are shown in fig.- 6.



*fig.- 6 : Different types of lenses*

A lens may have two spherical surfaces bulging outwards. Such a lens is called double convex lens (Biconvex lens, see fig.- 6(a)). It is thick at the middle as compared to edges.

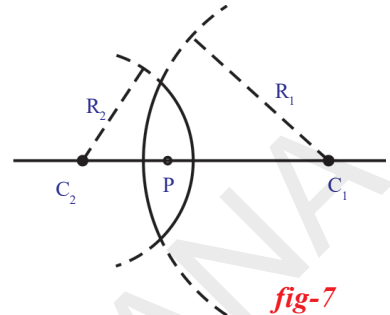
Similarly, a double concave lens is bounded by two spherical surfaces curved inwards. (Biconcave lens, see fig.- 6(d)). It is thin at the middle and thicker at the edges.

Observe the 6(c), 6(b), 6(e) and 6(f) to understand structure of Concavo-Convex lens, Plano-Convex lens, Plano-Concave lens and Convexo-concave lens.

Here we are concerned only with thin lenses i.e. the thickness of the lens is negligible.

Let us learn the terminology used in the case of lenses.

Each curved surface of a lens is part of a sphere. The centre of the sphere which contains the part of the curved surface is called *centre of curvature*. It is denoted by a letter 'C'. If a lens contains two curved surfaces then their centres of curvature are denoted as  $C_1$  and  $C_2$ . The distance between the centre of curvature and curved surface is called *radius of curvature* ( $R$ ). Radii of curvature are represented by  $R_1$  and  $R_2$  respectively. Let us consider a double convex lens as shown in fig.- 7.



The line joining the points  $C_1$  and  $C_2$  is called *principal axis*. The *midpoint of a thin lens* is called *optic centre* of lens (P).

### Focal length of the lens

A parallel beam of light incident on a lens converges to a point as shown in fig.- 8(a) or seems to emanate from a point on the principal axis as shown in fig.- 8(b). The point of convergence (or) the point from which rays seem to emanate is called *focal point* or *focus* (F). Every lens has two focal points. The distance between the focal point and optic centre is called the *focal length* of lens denoted by 'f'.

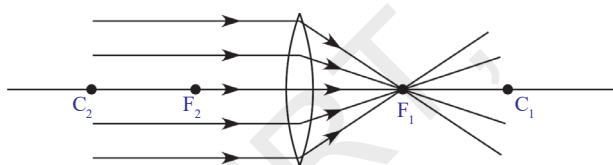


fig-8(a)

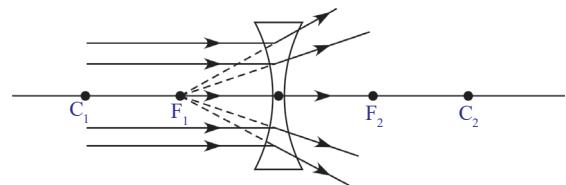


fig-8(b)

For drawing ray diagrams related to lenses we represent convex lens with a symbol  $\updownarrow$  and concave lens with  $\nabla$ . See figures 8(c) and 8(d).

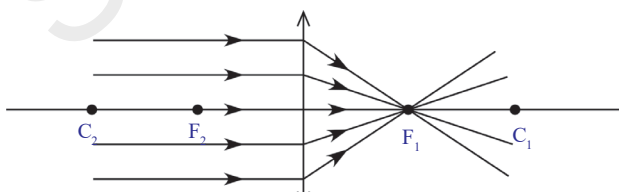


fig-8(c)

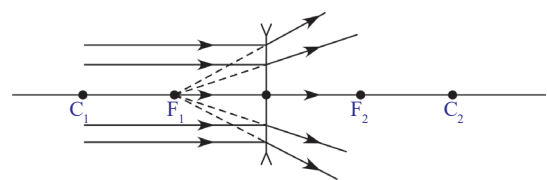


fig-8(d)

- How does the lens form an image?

To know the formation of image by lenses, we need to know the behaviour of light rays when they meet a lens.

Though we know that the lens has two surfaces; while drawing ray diagrams, we can consider the lens as a single surface element because we assume that the thickness of the lens is very small and show the net refraction at only one of the surfaces, as shown in the fig.- 8(c) and 8(d).

### Behaviour of certain light rays when they are incident on a lens

The behaviour of a light ray when it passes through a lens can be understood by observing its behaviour in the following situations:

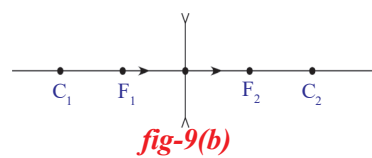
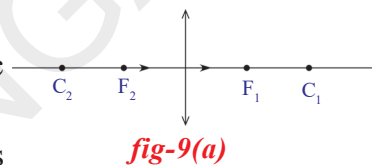
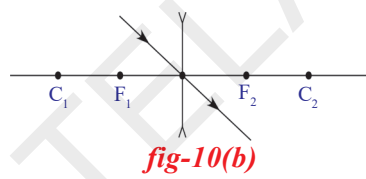
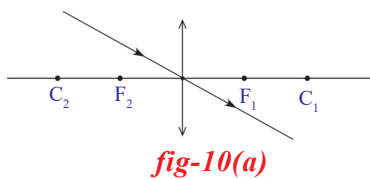
**Note:** The points  $C_1, C_2$  are not centre of curvatures. They are the points at '2f' distances from optic centre.

#### Situation I: Ray passing along the principal axis

Any ray passing along the principal axis is undeviated. (see Figures 9a and 9b)

**Situation II: Ray passing through the optic centre.**

Any ray passing through the optic centre is also undeviated. (see Figure 10a and 10b)



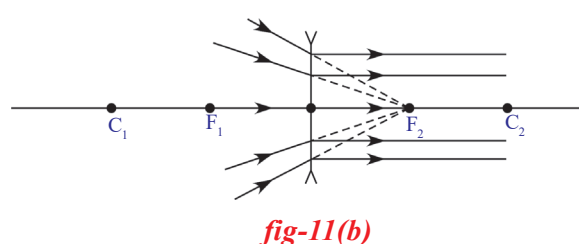
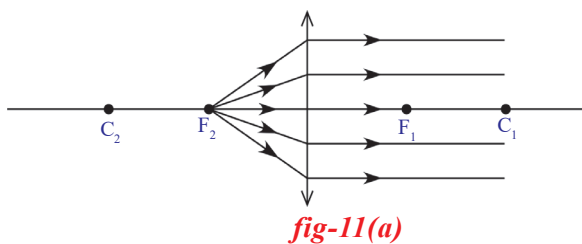
#### Situation III: Rays travelling parallel to the principal axis.

We know that the rays passing parallel to the principal axis converge at the focus or appear to diverge from the focus as shown in fig.- 8(c) and 8(d).

- If we allow a light ray to pass through the focus, which path does it take?

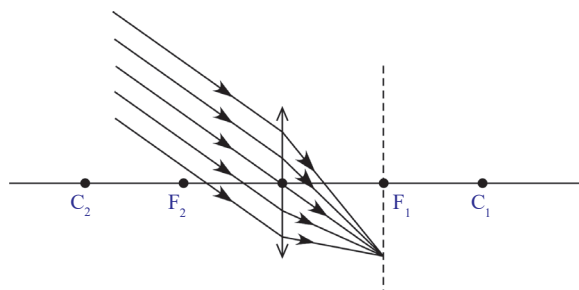
#### Situation IV: Ray passing through focus.

Light rays obey the principle of least time. Hence the ray passing through the focus will take a path parallel to principal axis after refraction. (see Figure 11(a) and 11(b))

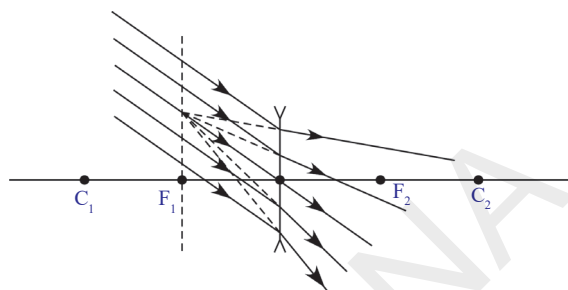


- What happens when parallel rays of light fall on a lens making some angle with the principal axis?

Let us observe the following figures



*fig-12(a)*



*fig-12(b)*

When parallel rays, making an angle with principal axis, fall on a lens, as shown in figures 12(a) and 12(b), the rays converge at a point or appear to diverge from a point lying on the focal plane. Focal plane is the plane perpendicular to the principal axis at the focus.

### Rules to draw ray diagrams for image formation by lenses

Let us learn a few basic rules to draw ray diagrams to locate the position of images.

For drawing a ray diagram to find position and size of the image formed by lens for any position of object on the principal axis you need to follow the rules mentioned below:

For locating position and to find the size of image, we need two rays out of four rays that were mentioned in the situations I to IV.

- Select a point on the object placed at a point on the principal axis.
- Draw two rays that were chosen by you from rays mentioned in situations I to IV.
- Extend both rays to intersect at a point. This point gives position of the image.
- Draw a normal from point of intersection to the principal axis.
- Length of this normal represents the size of the image.

Observe the following diagrams (situations 1-6). They represent image formation by a convex lens for various positions of the object.

#### 1. Object at infinity

- What do you mean by an object at infinity?
- What type of rays fall on the lens?

You know that the rays falling on the lens from an object at infinity are parallel to the principal axis.

They converge to the focal point. So a point sized image is formed at the focal point. This can be seen in fig.-s 8(a).

## 2. Object placed beyond the centre of curvature on the principal axis

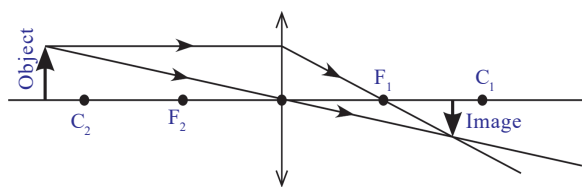


fig-13

In fig.- (13) you notice that when object is placed beyond the centre of curvature ( $C_2$ ), a *real, inverted and diminished* image is formed on the principal axis between the points  $F_1$  and  $C_1$ .

In fig.- (13) we have chosen two rays, one ray passing parallel to the principal axis and another ray passing through the optic centre to locate the position of the image.

Try to draw ray diagram using the pair of rays, one passing parallel to the axis another passing through the focus.

## 3. Object placed at the centre of curvature

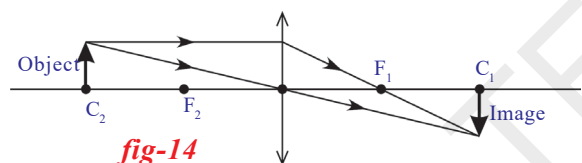


fig-14

When an object is placed at the centre of curvature ( $C_2$ ) on the principal axis, you will get an image at  $C_1$  which is *real, inverted* and of the *same size* as that of object. See fig.- 14.

## 4. Object placed between the centre of curvature and focal point

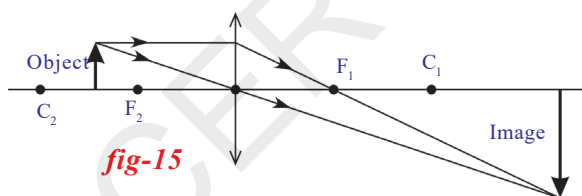


fig-15

When an object is placed between centre of curvature ( $C_2$ ) and focus ( $F_2$ ), you will get an image which is *real, inverted and magnified*. See fig.- 15. The image will form beyond  $C_1$ .

## 5. Object located at the focal point

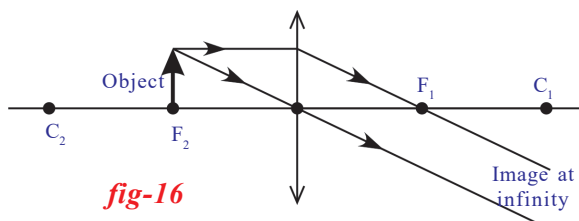


fig-16

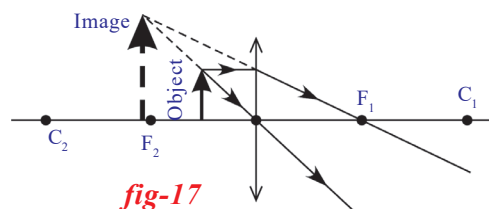
When an object is placed at focus ( $F_2$ ), the image will be at infinity. See fig.- 16. When the image is formed at an infinite distance away we can not discuss the size and nature of the image.



## 6. Object placed between focal point and optic centre

If we place an object between focus and optic centre, we will get an image which is *virtual*, *erect* and *magnified*.

From the ray diagram shown in fig.- 17, you will notice that the image formed is a *virtual*, *erect* and is formed on the same side of the lens where the object is placed. The size of the image is larger than that of the object. It is a *magnified image*.



In the above situation of image formation, we understand two things:

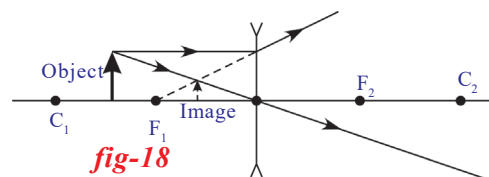
1. As the image formed is virtual, we can see it with our eyes. In all other cases the image is real which we can't see with our eyes but can be viewed if the image is captured on a screen.
2. A magnified virtual image is formed on the same side of the lens where the object is placed. Thus the image you are seeing through a lens is not real, it is a virtual image of the object.

This particular behaviour of convex lens helps to construct a microscope, which gives a magnified image. You might remember that the magnification of the virtual image is possible only when the object is at the distance less than the focal length of the lens.

Till now we have drawn ray diagrams for various positions of object placed on principal axis using convex lens. Draw ray diagram for an object placed between  $C_1$  and  $F_1$  for a concave lens.

- What do you notice?

Verify your ray diagram with the ray diagram we have drawn for a convex lens. See fig.- 18. Try to draw ray diagrams for other positions of an object. You will notice that irrespective of the position of object, on the principal axis, you will get an *erect*, *virtual image*, *diminished in size* in between the focal point and optic centre for concave lens.



Let us see a few examples of ray diagrams

### Example 4

Draw a ray diagram to locate the position of image when a point source (S) is placed on optical axis MN of a convex lens, in such a way that it is beyond focal point ( $F_2$ ). See fig.- E(4).

#### Solution

- Draw a perpendicular line to principal axis passing through the focus ( $F_1$ ).

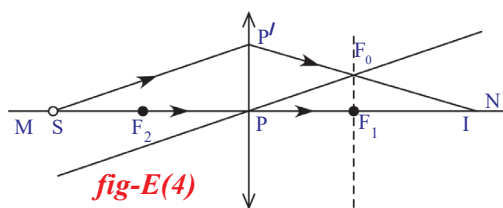


fig-E(4)

- Draw a ray from point source (S) in any direction to meet lens at point (P').
- Now draw another line parallel to the ray drawn from the point source (S) such that it passes through the optic centre (P); This line intersects the normal at point  $F_0$ .

- Now draw a line passing from point P' to pass through the point  $F_0$  such that it meets principal axis at a point say (I).
- 'I' is the image point for the point source (S).

### Example 5

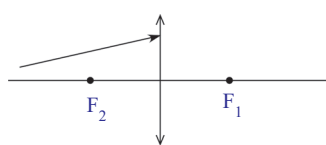


fig-E5(a)

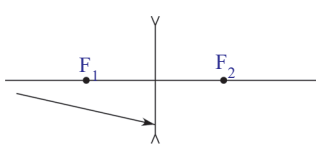


fig-E5(b)

Complete the ray diagram to show the paths of the rays after refraction through the lenses shown in the fig.-s E5(a) and E5(b)?

**Solution:** Follow the steps mentioned in Example (4) to complete the ray diagrams.

You will notice that the paths of the rays are shown in fig.-s E5(c) and 5(d).

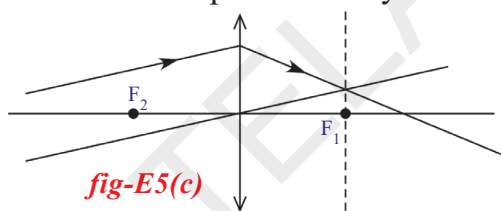


fig-E5(c)

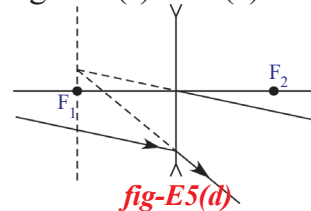


fig-E5(d)

- Can we realise in practice the results obtained in the ray diagrams when we perform experiments with a lens?

Let us see



### Lab Activity

**Aim:** Observing the types of images and measuring the object distance and image distance from the lens.

**Material required:** A candle, paper, convex lens (known focal length), V-stand, measuring tape or meter scale.

**Procedure:** Take a v-stand and place it on a long (nearly 2m) table at the middle. Place a convex lens on the v-stand. Imagine the principal axis of the lens. Light a candle and ask your friend to take the candle far away from the lens along the principal axis. Adjust a screen (a sheet of white paper placed perpendicular to the axis) which is on other side of the lens until you get an image on it.

- Why are we using a screen to view this image? Why don't we see it

directly with our eye?

Measure the distance of the image from the v-stand of lens and also measure the distance between the candle and stand of lens.

Record the values in a table 1.

Now place the candle at a distance of 60 cm from the lens, such that the flame of the candle lies on the principal axis of the lens. Try to get an image of the candle flame on the other side on a screen. Adjust the screen till you get a clear image. Measure the image

Object distance (u)	Image distance (v)	Focal length (f)

**Table 1**

distance (v) from lens and record the values of 'u' and 'v' in table 1. Repeat this for various object distances like 50 cm, 40 cm, 30 cm, etc. Measure image distances in all the cases and note them in table 1.

- Could you get an image on the screen for every object distance?
- Why don't you get an image for certain object distances?
- Can you find the minimum limiting object distance for obtaining a real image?
- What do you call this minimum limiting object distance for real images?

When you do not get an image on the screen, try to see the image with your eye directly from the place of the screen.

- Could you see the image?
- What type of image do you see?

You will see a magnified image on the same side where we kept the object. This is a *virtual* image of the object which we cannot capture on the screen.

- Can you find the image distance of this virtual image?

In table-1, you got different values of 'v' for various position of candle (u).

- Could you find focal length of the lens from the values recorded in table-1?
- Can we establish a relation between 'u', 'v' and 'f'?

Let us find out.

Consider an object  $OO^1$  placed on the principal axis in front of a convex lens as shown in fig.-(19). Let  $I I^1$  be the real image formed by the lens on the other side of it. Observe the fig.-(19).

- How is the image formed?

## Lens formula

The ray, starting at  $O^I$  and moving parallel to the principal axis and which falls on the lens, should pass through the focal point  $F_1$  as shown in fig.- (19). To locate the point of image ( $I^I$ ) for the object point ( $O^I$ ), consider another ray that passes through the optic centre  $P$ . We know that any ray passing through the optic centre  $P$  will not deviate.

The ray starting from  $O^I$  and passing through optic centre  $P$ , will meet the refracted ray (first ray) at the point  $I^I$ . This point is the image of the point  $O^I$  of the object. Similarly, the image of the point  $O$  on the principal axis is formed at point  $I$  on the principal axis (see Figure 19). We get the inverted image  $II^I$  of object  $OO^I$ .

$PO$ ,  $PI$  and  $PF_1$  are the object distance, image distance and focal length respectively. From fig.- 19, triangle  $PP^I F_1$  and triangle  $F_1 I I^I$  are similar triangles,

$$\Rightarrow PP^I/II^I = PF_1/F_1 I \quad \dots\dots\dots(1)$$

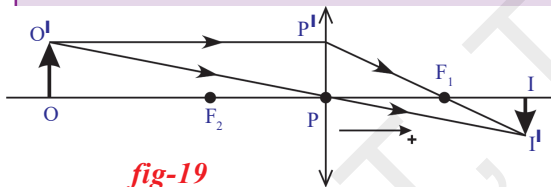
But from the fig.- 19,

$$F_1 I = PI - PF_1$$

substituting  $F_1 I$  in equation (1) above, we get

$$PP^I/II^I = PF_1/(PI - PF_1) \quad \dots\dots\dots(2)$$

We have another set of similar triangles  $OO^I P$  and  $PII^I$ .



From these triangles we get,  $OO^I/II^I = PO/PI$   
but from fig.- (19),  $OO^I = PP^I$ , hence we have

$$PP^I/II^I = PO/PI \quad \dots\dots\dots(3)$$

From (2) and (3), we get

$$PO/PI = PF_1/(PI - PF_1) \Rightarrow PI/PO = (PI - PF_1)/PF_1 \Rightarrow PI/PO = PI/PF_1 - 1$$

On dividing the equation by  $PI$ , we get

$$1/PO = 1/PF_1 - 1/PI \Rightarrow 1/PO + 1/PI = 1/PF_1$$

The above equation is derived for a particular case of the object while using a convex lens. To convert this into a general equation, we need to use the sign convention.

According to the sign convention

$$PO = -u ; PI = v ; PF_1 = f$$

Substituting these values in equation 4, we get

$$1/v - 1/u = 1/f$$

This equation is called *lens formula*. It can be used for any lens. But remember to use the sign convention while using this equation.

We have 'u' and 'v' values in table – 1 that were measured during activity – 2. Find focal length of the lens from the values of the table for each set of values of 'u' and 'v'.

## Magnification

Let us discuss the size of the image formed by a lens.

Observe object  $OO'$ , image  $II'$

in fig-20.

$\Delta OO'P, \Delta II'P$  are similar.

$$\therefore \frac{II'}{PI} = \frac{OO'}{PO} \Rightarrow \frac{II'}{OO'} = \frac{PI}{PO}$$

Substituting the values as per sign convention in the above equation, we get

$$\frac{-h_i}{h_o} = \frac{-v}{u}$$

$$\therefore \text{Magnification } m = \frac{h_i}{h_o} = \frac{v}{u}$$

- Is the focal length same for each set of values?

You might have noticed that irrespective of object distance and image distance, you will get same focal length. If you do not get the same value of focal length, there may be some experimental error while doing the experiment. In such a case, find the average of all the values. This will be equal to the focal length of the lens.

Let us see an example

### Example 6

An electric lamp and a screen are placed on the table, in a line at a distance of 1m. In what positions of convex lens of focal length of  $f = 21$  cm will the image of lamp be sharp?

#### Solution

The distance between the lamp and screen is 100cm and 'x' be the distance between lamp and lens. From fig.- E-6, we have  $u = -x$  and  $v = 100-x$ ,  $f = 21$

By substituting these in lens formula,

We get

$$\frac{1}{21} = \frac{1}{(100-x)} + \frac{1}{x}$$

After solving this equation, we get

$$x^2 - 100x + 2100 = 0$$

It is a quadratic equation. Hence we get two solutions. The solutions of the above equation are

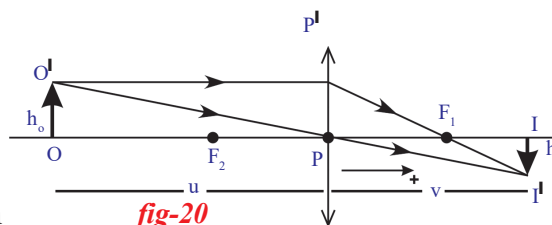


fig-20

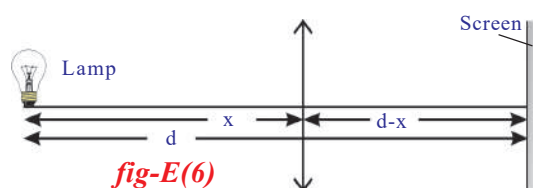


fig-E(6)

$$x^2 - 70x - 30x + 2100 = 0 \Rightarrow x(x - 70) - 30(x - 70) = 0 \Rightarrow (x - 70)(x - 30) = 0$$

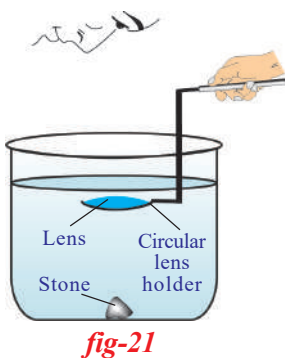
$$\therefore x = 70\text{cm and } x = 30\text{cm.}$$

We can place the lens at a distance of 70cm or 30cm from the bulb, we get sharp image.

- On what factors does the focal length of the lens depend?

Let us find out.

### Activity 2



Take the same lens that was used in lab activity. Note the average focal length of the lens that was calculated in the activity. Take a cylindrical vessel such as glass tumbler. Its height must be much greater than the focal length of the lens. (We require the vessel which has a length (depth) nearly equal to four times of the focal length of lens). Keep a black stone inside the vessel at its bottom. Now pour water into the vessel up to a height such that the height of the water level from the top of the stone is greater than focal length of lens. Now dip the lens horizontally using a circular lens holder as shown in the fig.- (21) above the stone. Set the distance between stone and lens that is equal to or less than focal length of lens measured in activity 2. Now look at the stone through the lens. (Do this in open ground)

- Can you see the image of the stone?
- If Yes / Not, why? Give your reasons.

You can see the image of the stone if the distance between lens and stone is less than the focal length of the lens (in air). Now increase the distance between lens and stone until you cannot see the image of the stone.

- What do you conclude from this activity?
- Does the focal length of the lens depend on surrounding medium?

You have dipped the lens to a certain height which is greater than the focal length of lens in air. But you can see the image (when lens is raised further, you could not see the image). This shows that the focal length of lens has increased in water. Thus we conclude that the focal length of lens depends upon the surrounding medium in which it is kept.

### Lens maker's formula

Imagine a point object 'O' placed on the principal axis of the thin lens as shown in fig.- 22. Let this lens be placed in a medium of refractive index  $n_a$  and let refractive index of lens medium be  $n_b$ .

Consider a ray, from 'O' which is incident on the convex surface of the lens with radius of curvature  $R_1$  at A as shown in fig.- 22.

The incident ray refracts at A.  
 Let us assume that, it forms image at Q, if there were no concave surface.

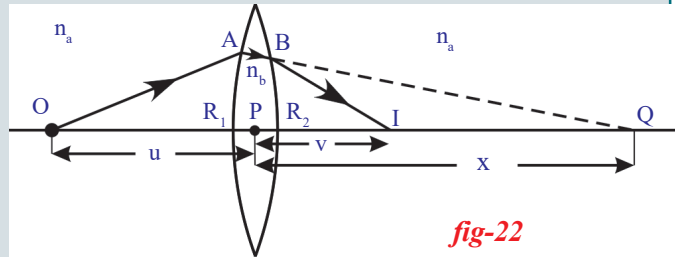


fig-22

From the fig.-(22), Object distance  $PO = -u$ ;

Image distance  $v = PQ = x$

Radius of curvature  $R = R_1$

$n_1 = n_a$  and  $n_2 = n_b$

Substitute the above values in the equation,  $n_2/v - n_1/u = (n_2 - n_1)/R$   
 $\Rightarrow n_b/x + n_a/u = (n_b - n_a)/R_1$  .....(1)

But the ray that has refracted at A suffers another refraction at B on the concave surface with radius of curvature ( $R_2$ ). At B the ray is refracted and reaches I on the principal axis.

The image Q of the object due to the convex surface is taken as object for the concave surface. So, we can say that I is the image of Q for concave surface. See fig.- 22.

Object distance  $u = PQ = +x$

Image distance  $PI = v$

Radius of curvature  $R = -R_2$

For refraction, the concave surface of the lens is considered as medium-1 and surrounding medium is considered as medium-2. Hence the suffixes of refractive indices interchange. Then we get,

$n_1 = n_b$  and  $n_2 = n_a$

Substituting the above values in equation  $n_2/v - n_1/u = (n_2 - n_1)/R$   
 $n_a/v - n_b/x = (n_a - n_b)/(-R_2)$  .....(2)

By adding (1) and (2) we get,

$\Rightarrow n_a/v + n_a/u = (n_b - n_a)(1/R_1 + 1/R_2)$

Dividing both sides by  $n_a$ , We get

$\Rightarrow 1/v + 1/u = (n_b/n_a - 1)(1/R_1 + 1/R_2)$

We know  $n_b/n_a = n_{ba}$  called refractive index of lens with respect to surrounding medium.

$1/v + 1/u = (n_{ba} - 1)(1/R_1 + 1/R_2)$

This is derived for specific case for the convex lens so we need to generalize this relation. For this we use sign convention. Applying sign convention to this specific case we get,

$1/v - 1/u = (n_{ba} - 1)(1/R_1 - 1/R_2)$

We know that

$$1/v - 1/u = 1/f$$

So, we get

$$1/f = (n_{ba} - 1)(1/R_1 - 1/R_2) \dots\dots\dots(3)$$

If the surrounding medium is air, then the relative refractive index could be absolute refractive index of the lens.

$$1/f = (n - 1)(1/R_1 - 1/R_2)$$

This can be used only when the lens is kept in air.

Where  $n$  is absolute refractive index and this equation is called lens maker's formula.

**NOTE:** Always use sign convention while using any formula derived in this chapter and the above formula can be used for any thin lens.

The convex lens behaves as a converging lens, if it is kept in a medium with refractive index less than the refractive index of the lens. It behaves like a diverging lens when it is kept in a transparent medium with greater refractive index than that of the lens.

For example an air bubble in water behaves like a diverging lens.

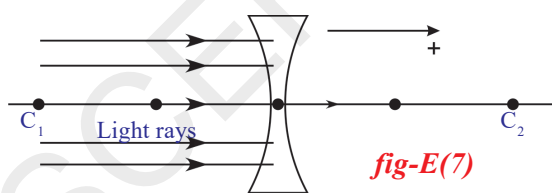
Let us see an example for lens maker formula.

### Example 7

What is the focal length of double concave lens kept in air with two spherical surfaces of radii  $R_1 = 30\text{cm}$  and  $R_2 = 60\text{cm}$ . Take refractive index of lens as  $n = 1.5$ .

**Solution:**

From the fig.- E-7 using sign convention we get



$R_1 = -30\text{cm}$ ,  $R_2 = 60\text{cm}$  and also given that  $n = 1.5$

using  $1/f = (n-1)(1/R_1 - 1/R_2)$

$$1/f = (1.5 - 1)[1/(-30) - 1/60]$$

Solving this, we get

$$f = -40\text{cm}$$

Here minus indicates that the lens is divergent.



### Key words

*Lens, Focal length, Focus, Optic centre, Principal axis, Radius of curvature, Centre of curvature, Focal plane.*





## What we have learnt

- The formula used when a light ray enters a medium with refractive index  $n_2$  from a medium with refractive index  $n_1$  at curved interface with a radius of curvature  $R$  is  $n_2/v - n_1/u = (n_2 - n_1)/R$
- A lens is formed when one medium is separated from another medium by two surfaces, one of which is curved.
- Lens formula is  $1/f = 1/v - 1/u$   
where  $f$  is the focal length of lens,  $u$  is the object distance and  $v$  is the image distance.
- Lens maker's formula is  $1/f = (n-1)(1/R_1 - 1/R_2)$   
where  $R_1$  and  $R_2$  are radii of curvature,  $n$  is the refractive index and  $f$  is the focal length.
- Characteristics of the image formed due to convex lens

Position of the object	Position of the Image	Characteristics of the image
At infinity	Focal Point ( $F_1$ )	Point Image
Beyond $C_2$	Between $F_1$ & $C_1$	Inverted, Diminished & Real
At $C_2$	On $C_1$	Inverted, Same size & Real
Between $F_2$ & $C_2$	Beyond $C_1$	Inverted, Magnified & Real
At $F_2$	Infinity	-
Between $F_2$ & P	Beyond $F_2$	Erect, Magnified & Virtual



## Improve your learning

### Reflections on concepts

1. How do you verify experimentally that the focal length of a convex lens is increased when it is kept in water? ( $AS_1$ )
2. How do you find the focal length of a lens experimentally? ( $AS_1$ )
3. Draw ray diagrams for the following positions and explain the nature and position of image.
  - i. Object is placed at  $C_2$
  - ii. Object is placed between  $F_2$  and optic centre P. ( $AS_5$ )



### Application of concepts

1. Two converging lenses are to be placed in the path of parallel rays so that the rays remain parallel after passing through both lenses. How should the lenses be arranged? Explain with a neat ray diagram. (AS<sub>1</sub>)
2. The focal length of a converging lens is 20cm. An object of 2cm height is at a distance of 60cm from the lens. Where will the image be formed and what kind of image is it? And also find the height of the image (AS<sub>1</sub>) (Ans: A real, diminished, inverted image formed at 30cm from the lens)
3. A double convex lens has two surfaces of equal radii 'R' and refractive index  $n = 1.5$ , find the focal length 'f'. (AS<sub>1</sub>)
4. Find the refractive index of the glass which is a symmetrical convergent lens if its focal length is equal to the radius of curvature of its surface. (AS<sub>7</sub>) (Ans: 1.5)

### Higher Order Thinking Questions



fig-Q(1)

- 1) A convex lens is made up of three different materials as shown in the fig-Q(1). How many of images does it form? (AS<sub>2</sub>)
- 2) You have a lens. Suggest an experiment to find out the focal length of the lens. (AS<sub>3</sub>)
- 3) Fig.-Q(3) shows ray AB that has passed through a divergent lens. Construct the path of the ray up to the lens if the position of its foci is known. (AS<sub>5</sub>)

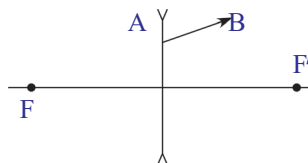
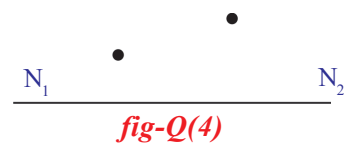
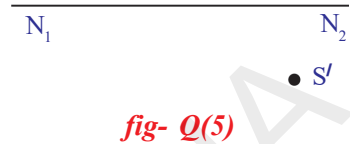


fig- Q(3)

- 4) Fig. -Q(4) shows a point light source and its image produced by a lens with an optical axis  $N_1N_2$ . Find the position of the lens and its foci using a ray diagram. (AS<sub>5</sub>)



- 5) Find the focus by drawing a ray diagram using the position of source S and the image S' given in the fig.-Q(5). (AS<sub>5</sub>)



- 6) A parallel beam of rays is incident on a convergent lens with a focal length of 40cm. Where a divergent lens with a focal length of 15 cm should be placed for the beam of rays to remain parallel after passing through the two lenses? Draw a ray diagram. (AS<sub>5</sub>)
- 7) Suppose you are inside the water in a swimming pool near an edge. A friend is standing on the edge. Do you find your friend taller or shorter than his usual height? Why?(AS<sub>7</sub>)

### Multiple choice questions

- 1) Which one of the following materials cannot be used to make a lens? [     ]  
 a) water    b) glass        c) acrylic        d) clay
- 2) Which of the following is true? [     ]  
 a) the distance of virtual image is always greater than the object distance for convex lens  
 b) the distance of virtual image is not greater than the object distance for convex lens  
 c) convex lens always forms a real image  
 d) convex lens always forms a virtual image
- 3) Focal length of the plano-convex lens is ..... when its radius of curvature of the surface is R and n is the refractive index of the lens. [     ]  
 a)  $f = R$             b)  $f = R/2$     c)  $f = R/(n-1)$     d)  $f = (n-1)/R$

### Suggested Experiments

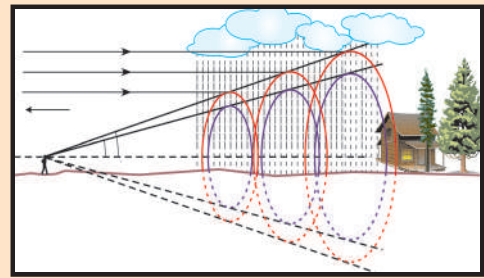
- 1) Conduct an experiment to find out the focal length of the lens.
- 2) Let us assume a system that consists of two lenses with focal length  $f_1$  and  $f_2$  respectively. How do you find the focal length of the system experimentally, when
  - i) two lenses are touching each other
  - ii) they are separated by a distance 'd' with common principal axis.

### Suggested Projects

1. Collect the information about the lenses available in an optical shop. Find out how the focal length of a lens may be determined by the given 'power' of the lens.
2. Take two watch glasses and affix them. Pour two different liquids (Ex. Water, Navaratan oil) and now it will act like a lens with two different materials. Put a light source (object) in front of this lens and note the observations and write a report on it.

## Chapter

# 5



# Human Eye and Colourful world

You have studied refraction of light through lenses in the previous chapter. You have learnt about nature, position and relative size of image formed by lenses for various distances of objects. In class IX, chapter VI on sense organs in Biological science text book, explained the structure of the human eye. The human eye functions on the principle of sensation of vision. We see objects because the light scattered from them falls on the eye. The eye has a lens in its structure.

In the previous chapter, you learned that the focal length of lens and object distance determine the nature, position and size of image.

- What is the function of lens in human eye?
- How does it help to see objects at long distances and short distances?
- How is it possible to get the image at the same distance on the retina?
- Are we able to see all objects in front of our eye clearly?
- How do the lenses used in spectacles correct defects of vision?

To answer these questions, you need to understand the structure and functioning of the human eye.

Let us do the following activities to know about some interesting facts about our vision.

### Least distance of distinct vision

#### Activity 1

Take a text book and hold it with your hands in front of you at a certain distance. Now try to read the contents on the page. Slowly move the book towards your eye till it is very close to your eyes.

- What changes do you notice?

You may see that printed letters on the page of the text book appear blurred or you feel strain in the eye.

Now slowly move the book backwards to a position where you can see clear printed letters without straining your eye. Ask your friend to measure the distance between your eye and text book at this position. Note down its value. Repeat the activity with other friends and note down the distances for distinct vision in each case.

Find the average of all these distances of clear vision.

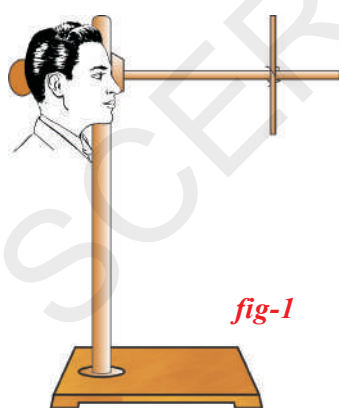
- What value do you get for average distance?

From this activity you will come to know that to see an object comfortably and distinctly, you must hold it at a distance about 25 cm from your eyes. This distance is called least distance of distinct vision. This varies from person to person and with age. At a young age (say below 10 years) the muscles around the eye are strong and flexible and can bear more strain. Therefore the least distance of distinct vision at this age is as close as 7 to 8 cm. Generally for a healthy person the least distance of distinct vision is around 25 cm. In old age the muscles cannot sustain more strain hence the least distance of distinct vision shifts to a larger value, say, about 1 to 2 m or even more.

- Are you able to see the top and bottom of an object placed at a distance of about 25 cm from your eye irrespective of its shape?

Let us find out.

## Activity 2



Collect a few wooden sticks used in cloth roller in clothes store (or) collect waste PVC pipes that are used for electric wiring. Prepare sticks or pipes of 20 cm, 30 cm, 35 cm, 40 cm, 50 cm from them. Place a retort stand on a table and stand near the table such that your head is beside the vertical stand (see fig 1). Adjust the clamp on the horizontal rod and fix it at a distance of 25 cm from your eyes. Ask one of your friends to fix a wooden stick of 30 cm height to the clamp in a vertical position as shown in fig1.

Now keeping your vision parallel to horizontal rod of the stand, try to see the top and bottom of wooden stick kept in vertical position.

- Are you able to see both ends of the stick simultaneously without any movement (shaking) in your eyes?

In activity-1, you learned that least distance for distinct vision is about 25 cm. It varies from person to person. If you are not able to see both end of the stick at this distance (25 cm), adjust the vertical stick on the horizontal rod till you are able to see both ends of the stick at the smallest possible distance from your eye. Fix the vertical stick at this position with the help of the clamp.

Without changing the position of the clamp on the horizontal rod, replace this stick of 30 cm length with other sticks of various lengths one by one and try to see the top and bottom of the stick simultaneously without any change in the position of eye either upwards downwards or side ways.

- Are you able to see both ends of the sticks in all these cases? If not why?

Let us know.

Observe the following fig.-2. You can see the whole object AB which is at a distance of 25 cm (least distance of distinct vision) because the rays coming from the ends A and B of the object AB will enter the eye. Similarly you can also see whole object CD with eye as explained above. Let us assume that AB moves closer to the eye to a position A'B' as shown in fig.2.

- Will you be able to see the whole object now?

From the fig.-2, you notice that you will be able to see only the part (EF) of the object A'B' because the rays coming from E and F enter your eye. The rays coming from A' and B' cannot enter your eye.

The rays coming from the extreme ends of an object form an angle at the eye. If this angle is below  $60^\circ$ , we can see the whole object. If this angle is above  $60^\circ$ , then we can see only the part of the object.

This maximum angle, at which we are able to see the whole object is called angle of vision. The angle of vision for a healthy human being is about  $60^\circ$ . It varies from person to person with the age.

You have learnt that the value of least distance of distinct vision is about 25 cm and the value of angle of vision of human beings is about  $60^\circ$ . You also learnt that these values change from person to person and with age of person.

- Why do the values of least distance of distinct vision and angle of vision change with person and age?

To answer the above question, we need to understand the structure of eye and its functioning.

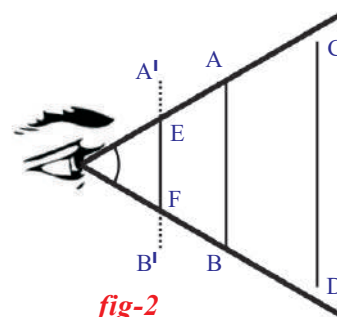
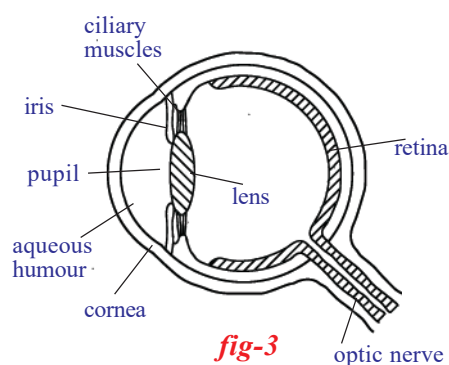


fig-2



## Structure of human eye

The human eye is one of the most important sense organs. It enables us to see the object and colours around us.

Fig.-3 shows schematically the basic components of human eye. The eye ball is nearly spherical in shape. The front portion is more sharply curved and is covered by a transparent protective membrane called the ‘cornea’. It is this portion which is visible from outside. Behind the cornea, there is place filled with a liquid called aqueous humour and behind this a crystalline lens which is responsible for the image formation. Between the aqueous humour and the lens, we have a muscular diaphragm called ‘iris’ which has a small hole in it called pupil. Iris is the coloured part that we see in an eye.

The pupil appears black because any light falling on it goes into the eye and there is almost no chance of light coming back to the outside. Iris helps in controlling the amount of light entering the eye through ‘pupil’. In low light condition, the iris makes the pupil to expand so that more light is allowed to go in and in the case of bright (or) excess light condition, it makes the pupil contract and there by prevent the excess light not to go into eye. Thus ‘iris’ enables pupil to act as a “variable aperture” for entry of light into the eye.

The lens is hard in the middle and gradually becomes soft towards the outer edge. The light that enters the eye forms an image on the retina. (It covers the rear part of eyeball). The distance between the lens and retina is about 2.5 cm i.e., for any position of object in front of the eye the image distance is fixed and about 2.5 cm.

- How can we get this same image distance for various positions of objects?
- Can you answer this question using concepts of refraction through lenses?

In the previous chapter, you have learnt that for different positions of object, the image distance remains constant only when there is a change in focal length of lens. Further, the focal length of a lens depends on the material by which it has been made and radii of curvature of lens. We need to change focal length of eye lens to get same image distance for various positions of object in front of the eye. This is only possible when the eye lens is able to change its shape.



- How does eye lens change its focal length?
- How does this change take place in the eye ball?

Let us know

The ciliary muscle to which eye lens is attached (see fig-3) helps the eye lens to change its focal length by changing the radii of curvature of the eye lens.

When the eye is focussed on a distant object, the ciliary muscles are relaxed so that the focal length of eye lens has its maximum value which is equal to its distance from the retina. The parallel rays coming into the eye are then focussed on to the retina and we see the object clearly.

When the eye is focussed on a closer object, the ciliary muscles are strained and focal length of eye-lens decreases. The ciliary muscles adjust the focal length in such a way that the image is formed on retina and we see the object clearly. This process of adjusting focal length is called “accommodation”. However these muscles cannot strain beyond a limit and hence if the object is brought too close to eyes, the focal length cannot be adjusted to form an image on the retina. Thus there is a minimum distance for distinct vision of an object which is roughly equal to 25 cm as we have learned in activity-1.

- Does eye lens form a real image or virtual image?
- How does the image formed on retina help us to perceive the object without change in its shape, size and colour?

Let us know

The eye-lens forms a real and inverted image of an object on the retina. The retina is a delicate membrane, which contains about 125 million receptors called ‘rods’ and ‘cones’ which receive the light signal (cones-identify the colour: rods-identify the intensity of light). These signals are transmitted to the brain through about 1 million optic-nerve fibres. The brain interprets these signals and finally processes the information so that we perceive the object in terms of its shape, size and colour.

In our previous discussion, you have learnt that eye-lens itself changes its focal length in accordance with distance of the object with the help of ciliary muscles.

- Is there any limit to the change of focal length of the eye-lens?
- What are the maximum and minimum focal lengths of the eye lens?  
How can we find them?

Let us find

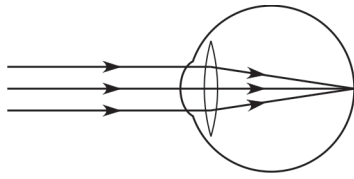


fig-4(a)

When the object is at infinity, the parallel rays from the object falling on the eye lens are refracted and they form a point sized image on retina (see fig-4(a)).

In this situation, eye-lens has a maximum focal length.

When the object is at infinity,

$u = -\infty$ ;  $v = 2.5$  cm (image distance which is equal to distance between eye-lens and retina)

using the formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{f_{\max}} = \frac{1}{2.5} + \frac{1}{\infty}$$

$$\frac{1}{f_{\max}} = \frac{1}{2.5} + 0$$

$$f_{\max} = 2.5 \text{ cm}$$

we get,

$$f_{\max} = 2.5 \text{ cm}$$

consider that an object is placed at distance of 25 cm from our eye. In this situation eye has minimum focal length.

Here  $u = -25$  cm;  $v = 2.5$  cm

Using the formula  $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

$$\frac{1}{f_{\min}} = \frac{1}{2.5} + \frac{1}{25}$$

$$\frac{1}{f_{\min}} = \frac{11}{25}$$

$$\frac{1}{f_{\min}} = \frac{25}{11} = 2.27 \text{ cm}$$

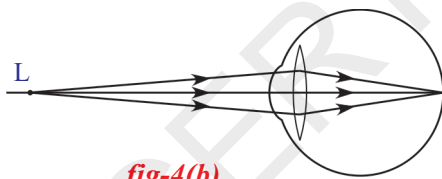


fig-4(b)

If the position of an object is between infinity and the point of least distance of distinct vision, then the eye lens adjusts its focal length in between 2.5 cm to 2.27 cm to form a clear image on the retina.

The ability of eye-lens to change its focal length is called “accommodation of lens”.

- What happens if the eye lens is not able to adjust its focal length?
- What happens if the focal length of eye lens is beyond the range of 2.5 cm to 2.27 cm?

Let us find out.

Sometimes the eye may gradually lose its ability for accommodation. In such conditions the person cannot see an object clearly and comfortably. The vision becomes blurred due to accommodation defects of the eye lens. There are mainly three common defects of vision.

They are:

- i. Myopia
- ii. Hypermetropia
- iii. Presbyopia.

## Myopia

Some people cannot see objects at long distances but can see nearby objects clearly. This type of defect in vision is called 'Myopia'. It is also called 'near sightedness'. For these people the maximum focal length is less than 2.5 cm. In such cases the rays coming from distant objects, after refraction through the eye lens, form an image before the retina as shown in figures-5(a) and (b).

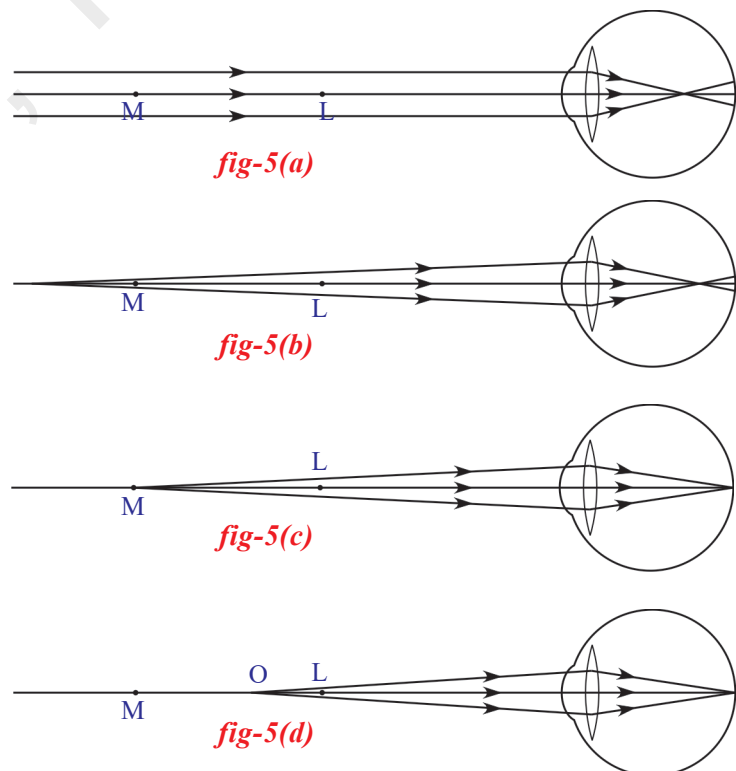
A healthy person can see objects at all distances more than 25 cm clearly but a person with myopia can see objects clearly up to a certain distance. Let the extreme point from where an object appears clearly to a person with myopia be 'M' (shown in fig.-5(c)).

If the object is at M or in between M and point of least distance of distinct vision (L), the eye lens can form an image on the retina (see fig.-5(c) and 5(d)). This point M is called 'far point'.

The point of maximum distance at which the eye lens can form an image on the retina is called 'far point'.

The defect, in which people cannot see objects beyond far point is called 'Myopia'.

- What can we do to correct myopia?



The eye lens can form clear image on the retina, when an object is placed between far point and point of least distance of distinct vision. If we are able to bring the image of the object kept beyond far point , between

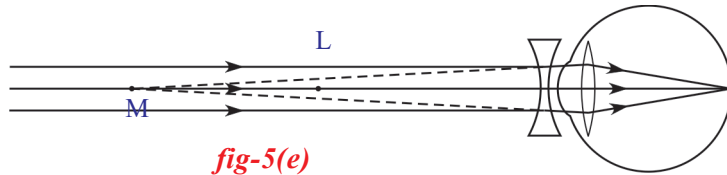


fig-5(e)

the far point and the point of least distance of distinct vision using a lens, this image acts as an object for the eye lens.

This can be made possible only when a concave lens is used (recollect image formation by refraction through a concave lens).

- How can you decide the focal length of the lens to be used to correct myopia?

To correct one's Myopia, we need to select a lens which forms an image at the far point for an object at infinity. We need to select bi-concave lens to achieve this.

This image acts like an object for the eye lens. Hence the final image is formed on the retina.

Let us find the focal length of this bi-concave lens.

Here object distance ( $u$ ) is infinity and image distance ( $v$ ) is equal to distance of far point.

$$u = -\infty ; v = \text{distance of far point} = -D$$

let 'f' be the focal length of bi-concave lens.

$$\text{Using lens formula, } \frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{f} = \frac{1}{-D} \Rightarrow f = -D$$

Here 'f' is negative showing that it is a concave lens.

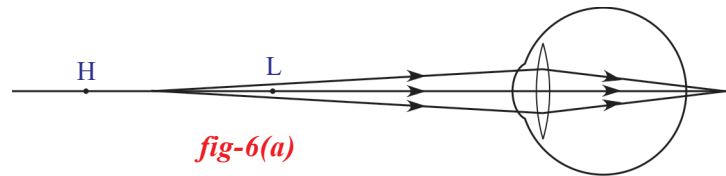
- What happens when the eye has a minimum focal length greater than 2.27 cm?

Let us find out.

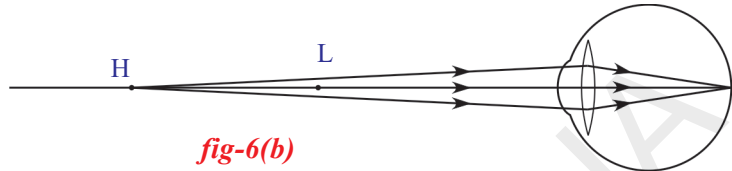
## Hypermetropia

Hypermetropia is also known as "far sightedness". A person with hypermetropia can see distant objects clearly but cannot see objects at near distances, because the minimum focal length of eye lens for the person of hypermetropia is greater than 2.27 cm. In such cases, the rays coming

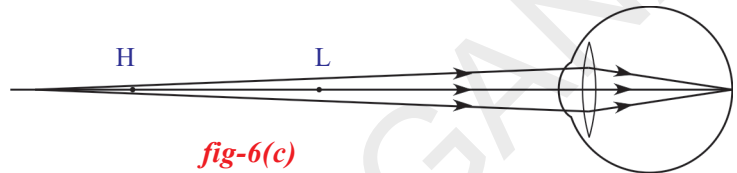
from a nearby object, after refraction at eye lens, forms an image beyond the retina as shown in fig.- 6 (a).



Let the point of least distance at which the eye lens forms a clear image on the retina for a person with hypermetropia be 'H'. See fig.- 6(b).



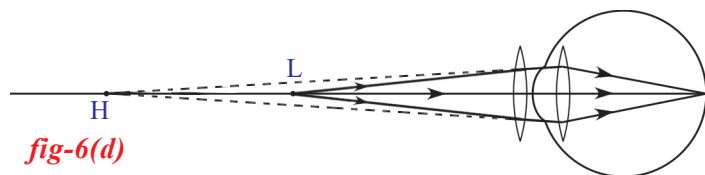
If an object is at H or beyond H, the eye can form its image on retina (see figures 6(b) and 6(c)). If the object is between H and point of least distance of distinct vision (L) then it cannot form an image. See fig.- 6(a).



The point of minimum distance at which the eye lens can form an image on the retina is called near point (d). The people with defect of hypermetropia cannot see objects placed between near point (H) and point of least distance of distinct vision (L).

- How can you correct this defect?

Eye lens can form a clear image on the retina when any object is placed beyond near point. To correct the defect of hypermetropia, we need to use a lens which forms an image of an object beyond near point, when the object is between near point (H) and least distance of distinct vision (L).



This is possible only when a double convex lens is used.

- How can you decide the focal length of the convex lens to be used?

To find the focal length of lens, let us consider that the object is at point of least distance of distinct vision (L). Then the defect of vision, hypermetropia, is corrected when the image of the object at L is formed at the near point (H) by using a bi-convex lens as shown in fig.-6(d).

This image acts like an object for the eye lens. Hence final image due to eye is formed at retina (see fig.- 6(d))

Here object distance (u) = -25 cm

Image distance (v) = distance of near point = -d

Let 'f' be the focal length of bi-convex lens.

Using lens formula,  $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

$$\frac{1}{f} = \frac{1}{-d} - \frac{1}{-25}$$

$$\frac{1}{f} = -\frac{1}{d} + \frac{1}{25}$$

$$\frac{1}{f} = \frac{(d-25)}{25d}$$

$$f = \frac{25d}{(d-25)} \text{ (f is measured in centimeters)}$$

we know that if  $d > 25\text{cm}$ , then 'f' becomes +ve i.e., we need to use biconvex lens to correct defect of hypermetropia.

### Presbyopia

Presbyopia is vision defect when the ability of accommodation of the eye usually decreases with ageing. For most people the near point gradually recedes away. They find it difficult to see nearby objects clearly and distinctly.

This happens due to gradual weakening of ciliary muscles and diminishing flexibility of the eye lens. This effect can be seen in aged people. Sometimes a person may suffer from both myopia and hypermetropia with ageing.

To correct this type of defect of vision we need bi-focal lenses which are formed using both concave and convex lenses. Its upper portion consists of the concave lens and lower portion consists of the convex lens.

If you go to an eye hospital to get tested for vision defects, the doctor gives you a prescription that contains some information regarding type of lens to be used to correct vision.

- Have you ever observed details in the prescription?

You might have heard people saying "my sight is increased or decreased".

- What does it mean?

Usually doctors, after testing for defects of vision, prescribe corrective lenses indicating their power which determines the type of lens to be used and its focal length.

- What do you mean by power of lens?

### Power of lens:

The degree of convergence or divergence of light rays that can be achieved by a lens is expressed in terms of its power.

The reciprocal of focal length is called power of lens.

Let 'f' be the focal length of lens.

$$\text{Power of lens } P = \frac{1}{f} \text{ (in m); } P = \frac{100}{f} \text{ (in cm)}$$

The unit of power is dioptre.

It is denoted by the letter 'D'.

### Example1

Doctor advised to use 2D lens. What is its focal length?

**Solution:** Given that power of lens  $P = 2D$

$$\text{Using, } P = \frac{100}{f} \text{ (in cm); } 2 = \frac{100}{f}$$

$$\text{Therefore, } f = \frac{100}{2} = 50 \text{ cm.}$$

The lens has focal length,  $f = 50 \text{ cm}$ .

## Dispersion and Scattering of Light

You might have seen a rainbow form in the sky just after a rain shower. It must have fascinated you with spectacular colours appearing as a semi-circular band of colours.

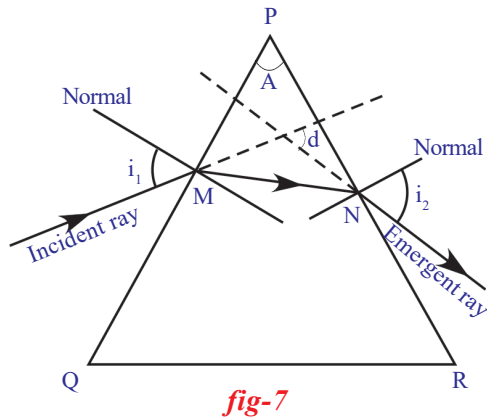
- How could the white light of the sun give us various colours of the rainbow?

In previous chapters, you have studied the behaviour of light when it refracts through plane surface and curved surfaces, such as a lens. You also studied the nature, position and relative size of image formed by lenses.

- What happens to a light ray when it passes through a transparent medium bounded by plane surfaces which are inclined to each other?
- What is a prism?

## Prism

A prism is a transparent medium separated from the surrounding medium by at least two plane surfaces which are inclined at a certain angle in such a way that, light incident on one of the plane surfaces emerges from the other plane surface. To understand the behaviour of light when it is incident on a plane of prism and passes through the prism, we need to define certain terms associated with prisms.



Consider a triangular glass prism. It contains two triangular bases and three rectangular plane lateral surfaces. These lateral surfaces are inclined to each other.

Let us consider that triangle PQR represents outline of the prism where it rests on its triangular base. Let us assume that a light ray is incident on the plane surface PQ of a prism at M as shown in fig.-7. Draw a perpendicular to the surface at M. It becomes a normal to that surface. The angle between the *incident ray* and normal is called *angle of incidence* ( $i_1$ ). The ray is refracted at M. It moves through prism and meets the other plane surface at N and finally comes out of the prism. The ray which comes out of the surface PR at N is called *emergent ray*. Draw a perpendicular to PR at point N. The angle between the emergent ray and normal is called *angle of emergence* ( $i_2$ ). The angle between the plane surfaces PQ and PR is called the *angle of the prism or refracting angle of prism A* and the angle between the incident ray and emergent ray is called *angle of deviation* ( $d$ ).

Let us now take up an activity to study the refraction of light through a triangular prism.



### Lab Activity

**Aim:** Finding the refractive index of a prism.

**Material required:** Prism, piece of white chart of size 20x20 cm, pencil, pins, scale and protractor.

**Procedure:** Take a prism and place it on the white chart in such a way that the triangular base of the prism is on the chart. Draw a line around the prism (boundary) using a pencil. Remove the prism.

- What is the shape of the outline drawn?



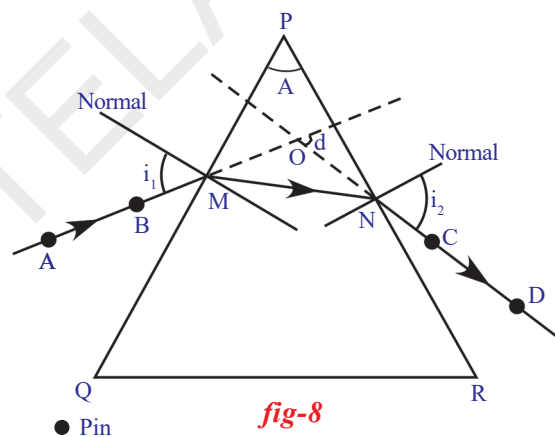
It is a triangle. Name its vertices as P,Q, and R.[for many prisms the triangle formed is equilateral]. The refracting surfaces could be rectangular in shape. Find the angle between PQ and PR . This is the angle of the prism (A).

Mark M on the side of triangle PQ and also draw a perpendicular to PQ at M. Place the centre of the protractor at M and along the normal. Mark an angle of  $30^\circ$  and then draw a line up to M. This line denotes the incident ray. This angle is called angle of incidence. Note it in a table (1). Draw a small arrow on it as shown in fig.- 8.

Place the prism in its position (triangle) again. Now fix two pins vertically on the line at points A and B as shown in fig.- 8. Look for the images of pins through the prism from the other side (PR) and fix another two pins at points C and D in such a way that all the four pins appear to lie along the same straight line. Do it carefully. Now remove the prism and take out pins. Draw a line joining the two pin-holes formed by the pins to meet surface 'PR', this is the emergent ray which 'emerges from' the surface PR at a point 'N'. The angle between the normal at N and the emergent ray is the angle of emergence. Measure this angle and note its value in the table (1).

**Table 1**

Angle of incidence ( $i_1$ )	Angle of emergence ( $i_2$ )	Angle of deviation (d)



Now join the points M and N by a straight line. The line passing through the points A,B, M,N,C and D represents the path of light when it suffers refraction through the prism.

- How do you find the angle of deviation?

Extend both incident and emergent rays till they meet at a point 'O'. Measure the angle between these two rays. This is the angle of deviation. It is denoted by a letter 'd'. Note it in table (1). Repeat this procedure for various angles of incidence such as  $40^\circ, 50^\circ$  etc. Find the corresponding angles of deviation and angles of emergence and note them in table (1).

- What do you notice from the angles of deviation?

You will notice that the angle of deviation decreases first and then increases with increase in the angle of incidence.

- Can you draw a graph between angle of incidence and angle of deviation?

Take angle of incidence along X- axis and the angle of deviation along Y- axis. Using a suitable scale, mark points on a graph paper for every pair of angles. Finally join the points to obtain a graph (smooth curve). Check your graph with graph shown in fig.- 9.

- From the graph, can you find the minimum of the angles of deviation?

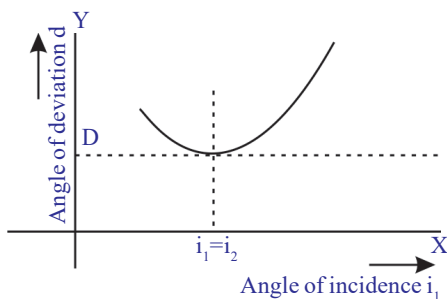


fig-9

Yes we can. Draw a tangent line to the curve, parallel to X- axis, at the lowest point of the graph. The point where this line cuts the Y- axis gives the angle of minimum deviation. It is denoted by D. Draw a parallel line to y-axis through the point where the tangent touches the graph. This line meets x-axis at a point showing the angle of incidence corresponding to the minimum deviation. If you do the experiment with this angle of incidence you will get an angle of emergence equal to the angle of incidence. Look at your table (1).

- Is there any relation between the angle of incidence, angle of emergence and angle of deviation?
- Can you find refractive index of a prism? If yes, how?

Let us find out.

### Derivation of formula for refractive index of a prism

Observe the ray diagram in the fig.- 10(a).

From triangle OMN, we get

$$d = i_1 - r_1 + i_2 - r_2$$

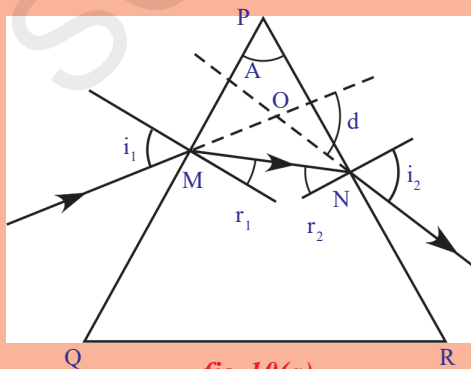


fig-10(a)

$$d = (i_1 + i_2) - (r_1 + r_2) \quad \text{--- (1)}$$

From triangle PMN, we have

$$A + (90^\circ - r_1) + (90^\circ - r_2) = 180^\circ$$

By simplification, we get

$$r_1 + r_2 = A \quad \text{--- (2)}$$

From (1) and (2), we have

$$d = (i_1 + i_2) - A$$

$$A + d = i_1 + i_2 \quad \text{--- (3)}$$

This is the relation between angle of incidence, angle of emergence, angle of deviation and angle of prism.

From Snell's law, we know that  $n_1 \sin i = n_2 \sin r$

Let  $n$  be the refractive index of the prism.

Using Snell's law at  $M$ , with refractive index of air

$n_1 = 1; i = i_1; n_2 = n; r = r_1$ , gives

$$\sin i_1 = n \sin r_1 \quad \text{---(4)}$$

similarly, at  $N$  with  $n_1 = n; i = r_2; n_2 = 1; r = i_2$ , gives

$$n \sin r_2 = \sin i_2 \quad \text{---(5)}$$

We know that at the angle of minimum deviation ( $D$ ), the angle of incidence is equal to the angle of emergence i.e.,  $i_1 = i_2$ . Observe fig.-10(b). You will note that  $MN$  is parallel to the side  $QR$ , actually ray  $MN$  is parallel to the base of the prism. (See fig.- 10(b)).

When  $i_1 = i_2$ , angle of deviation ( $d$ ) becomes angle of minimum deviation ( $D$ ).

Then equation (3) becomes

$$A + D = 2i_1$$

$$\text{or } i_1 = \frac{(A+D)}{2}$$

When  $i_1 = i_2$  then, it is clear that  $r_1 = r_2$

So from equation (2) we get,

$$2r_1 = A$$

$$\text{or } r_1 = \frac{A}{2}$$

Substituting  $i_1$  and  $r_1$  in (4) we get

$$\sin \left\{ \frac{(A+D)}{2} \right\} = n \cdot \sin \left( \frac{A}{2} \right)$$

$$\text{Therefore, } n = \frac{\sin \left\{ \frac{(A+D)}{2} \right\}}{\sin \left( \frac{A}{2} \right)} \quad \text{---(6)}$$

This is the formula for the refractive index of the prism.

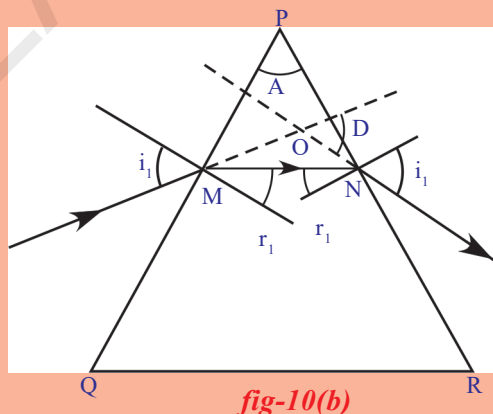


fig-10(b)

### Example 2

A prism with an angle  $A = 60^\circ$  produces an angle of minimum deviation of  $30^\circ$ . Find the refractive index of material of the prism.

**Solution:** Given that  $A = 60^\circ$  and  $D = 30^\circ$ .

$$\text{Using } n = \frac{\sin\left\{\frac{(A+D)}{2}\right\}}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left\{\frac{90^\circ}{2}\right\}}{\sin 30^\circ}$$

$$= \frac{\sin 45^\circ}{\sin 30^\circ} = \frac{1}{\sqrt{2}} \div \frac{1}{2} = \sqrt{2}$$

$$\Rightarrow n = \sqrt{2}$$

thus, the refractive index of the given prism =  $\sqrt{2}$

Let us take up a simple activity with prism.

### Activity 3

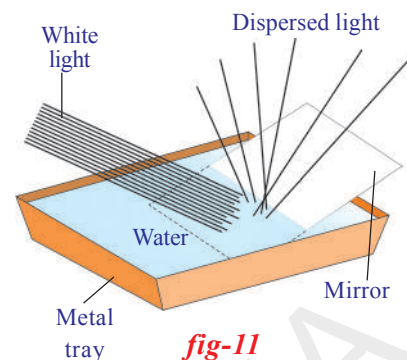
Do this activity in the dark room. Take a prism and place it on the table near a vertical white wall. Take a thin wooden plank. Make a small hole in it and fix it vertically on the table. Place the prism between the wooden plank and wall. Place a white light source behind the hole of the wooden plank. Switch on the light. The rays coming out of the hole of plank become a narrow beam of light. Adjust the height of the prism such that the light falls on one of the lateral surfaces. Observe the changes in emerged rays of the prism. Adjust the prism by slightly rotating it till you get an image on the wall.

- What do you observe on the wall?
- Could you get a coloured image on the wall?
- Why does white light split into colours?
- What colours do you see?
- Can you notice any change in the angle of deviation of each colour?
- Which colour has the minimum deviation?

Let us do another activity.

### Activity 4

Take a metal tray and fill it with water. Place a mirror in the water such that it makes an angle to the water surface. Now focus white light on the mirror through the water as shown in fig.- 11. Try to obtain colours on a white card board sheet kept above the water surface. Note the names of the colours you could see in your book.



In activity (3) and (4), we observe that white light is splitting into certain different colours.

- Is this splitting of white light into colours explained by using ray theory?

It is not possible to explain the splitting of white light into different colours using ray theory.

- Why is this so?

Let us see

### Dispersion of Light

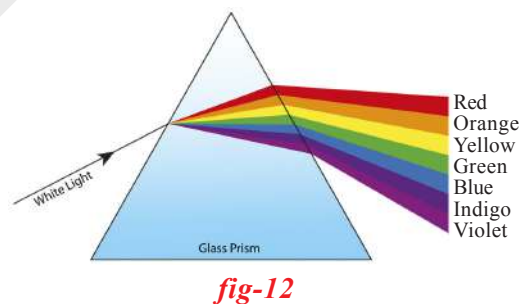
In activity 3, we observe that the angle of deviation is minimum for red as compared to the angles of deviation of other colours and maximum for violet.

The splitting of white light into different colours (VIBGYOR) is called **dispersion**.

In our previous discussion, we learnt that for a particular refractive index of prism there must be only one angle of minimum deviation and according to Fermat's principle, light ray always chooses the path of least time. But in activity-3, we noticed that light has chosen different paths.

- Does this mean that the refractive index of the prism varies from colour to colour?
- Is the speed of light of each colour different?

The situation we witnessed in activities (3) and (4) rule out ray theory of light. We can consider that white light is a collection of waves with different wavelengths. Violet colour is known to have the shortest wavelength while red is of the longest wavelength.



According to wave theory, light can be thought of a wave propagating in all directions. Light is an electromagnetic wave. Here no particle physically oscillates back and forth. Instead, the magnitude of electric and magnetic fields, associated with the electromagnetic wave, vary periodically at every point. These oscillating electric and magnetic fields propagate in all directions with the speed of light.

- Can you guess now, why light splits into different colours when it passes through a prism?

The reason lies in the fact that, while the speed of light is constant in vacuum for all colours, it depends on the wavelength of light when it passes through a medium. We know that refractive index is the ratio of speeds in vacuum and in the medium. Consequently, the refractive index of a medium depends on wavelength of light. When white light passes through a medium, each colour selects its least time path and we have refraction of different colours to different extents. This results in separation of colours, producing a spectrum on the wall and in the mirror as we saw in activities (3) and (4). It has been experimentally found that refractive index decreases with an increase in wavelength. If we compare the wave lengths of seven colours in VIBGYOR, red colour has longest wavelength and violet colour has shortest wavelength. The refractive index of red is low hence it suffers low deviation.

We noticed that when white light passes through a prism, it splits into seven colours. Let us assume that you have sent a single colour ray through the prism.

- Does it split into more colours? Why?

We know that the frequency of light is the property of the source and it is equal to number of waves leaving the source per second. This cannot be changed by any medium. Hence frequency doesn't change due to refraction. Thus coloured light passing through any transparent medium retains its colour.

While refraction occurs at the interface, the number of waves that are incident on the interface in a second must be equal to the number of waves passing through any point taken in another medium. This means that the frequency of the light wave remains unaltered while its wavelength changes depending on the medium through which it passes. We know that the relation between the speed of wave ( $v$ ), wavelength ( $\lambda$ ) and frequency ( $\nu$ ) is.

$$v = \nu \lambda \quad (\text{frequency denoted by } \nu)$$

For refraction at any interface,  $v$  is proportional to  $\lambda$ . Speed of the wave increases with increase in wavelength of light and vice versa.

- Can you give an example in nature, where you observe colours as seen in activity 3?

Your answer certainly is a rainbow. That is a good example of dispersion of light.

- When do you see a rainbow in the sky?
- Can we create a rainbow artificially?

Let us see how.

### Activity 5

Select a white coloured wall on which the sun rays fall. Stand in front of a wall in such a way that the sun rays fall on your back. Hold a tube through which water is flowing. Place your finger in the tube to obstruct the flow of water. Water comes out through the small gaps between the tube and your finger like a fountain. Observe the changes on the wall while the water shower is maintained; you can see colours on the wall.

- How is that you are able to see colours on the wall?
- Are the sun rays coming back to your eyes from the wall or from water drops?

Let us find out.

The beautiful colours of the rainbow are due to dispersion of the sunlight by millions of tiny water droplets. Let us consider the case of an individual water drop.

Observe fig.- 13. The rays of sunlight enter the drop near its top surface. At this first refraction, the white light is dispersed into its spectrum of colours, violet being deviated the most and red the least. Reaching the opposite side of the drop, each colour is reflected back into the drop because of total internal reflection. Arriving at the surface of the drop, each colour is again refracted into air. At the second refraction the angle between red and violet rays further increases when compared to the angle between those at first refraction.

The angle between the incoming and outgoing rays can be anything between  $0^\circ$  and about  $42^\circ$ . We observe bright rainbow when the angle between incoming and outgoing rays is near the maximum angle of  $42^\circ$ . Diagrammatically it is shown in fig.- 13. Although each drop disperses a

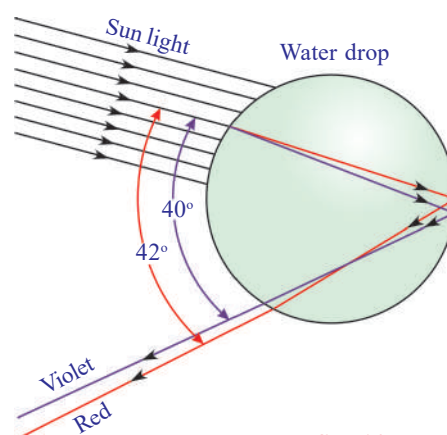


fig-13

full spectrum of colours, an observer is in a position to see only a single colour from any one drop depending upon its position.

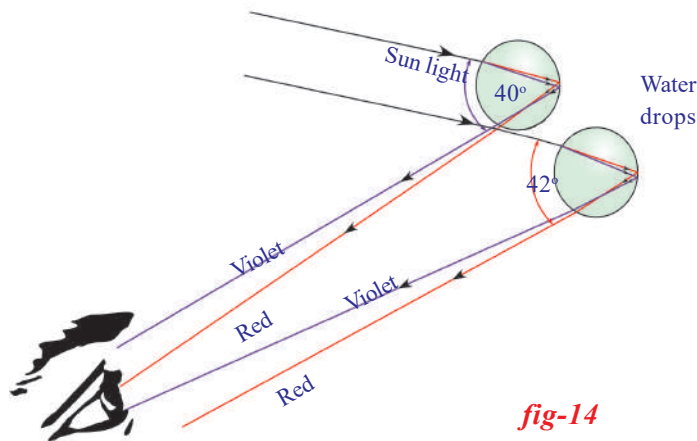


fig-14

sunlight and light sent back by a drop is  $42^\circ$ . The colour violet is seen when the angle between a sunbeam and light sent back by a drop is  $40^\circ$ . If you look at an angle between  $40^\circ$  and  $42^\circ$ , you will observe the remaining colours of VIBGYOR

- Why does the light dispersed by the raindrops appear as a bow?

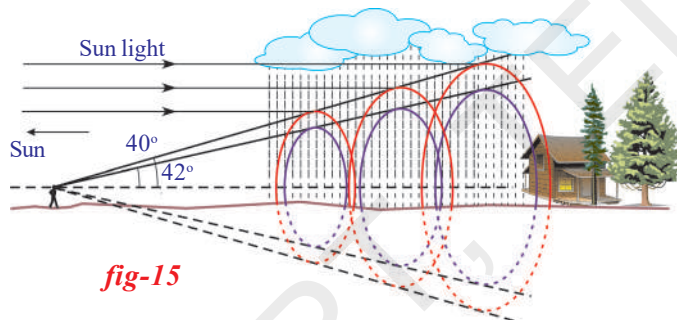


fig-15

your eye as shown in fig.- 15. All the drops that disperse the light towards you lie in the shape of the cone – a cone of different layers. The drops that disperse red colour to your eye are on the outer most layer of the cone, similarly the drops that disperse orange colour to your eye are on the layer of the cone beneath the red colour cone. In this way the cone responsible for yellow lies beneath orange and so on it till the violet colour cone becomes the innermost cone.(see in fig.- 15).

If violet light from a single drop reaches the eye of an observer, red light from the same drop can't reach his eye. It goes elsewhere possibly downwards of the eye of the observer (see in fig.- 14). To see red light, one must look at the drop higher in the sky. The colour red will be seen when the angle between a beam of

To find answer this question, we need a little geometric reasoning. First of all, a rainbow is not the flat two dimensional arc as it appears to us. The rainbow you see is actually a three dimensional cone with the tip at



### Think and discuss

- Can you imagine the shape of rainbow when observed during travel in an airplane?  
Discuss with your friends and collect information.



It is our common experience that the sky appears blue in colour on a bright dry day.

- Why is the sky blue?

To answer this question, you need to understand another phenomenon of light called scattering.

- What is scattering?

Let us see

## Scattering of Light

Scattering of light is a complex phenomenon. Let us try to understand the idea of scattering.

- Do you know what happens to the free atom or molecule when it is exposed to certain frequency of light?

Atoms or molecules which are exposed to light absorb light energy and emit some part of the light energy in different directions. This is the basic process happens in scattering of light.

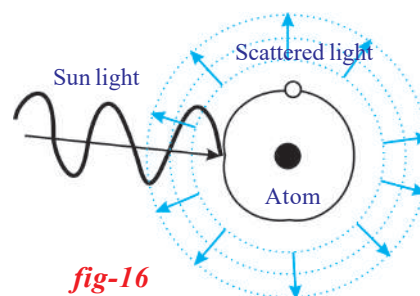
The effect of light on a molecule or an atom depends on the size of atom or molecule. If the size of the particle (atom or molecule) is small, it will be affected by higher frequency (lower wave length) light and vice versa.

Let us consider that a certain frequency of light is incident on an atom. Then the atom comes into vibration due to this light. This in turn releases or re-emits light in all directions with different intensity.

The intensity of light is the energy of light passing through unit area of plane, taken normal to the direction of propagation of light, in one second.

Let us consider that the free atom or free molecule is somewhere in space as shown in fig.- 16.

Light of certain frequency falls on that atom or molecule. This atom or molecule responds to the light whenever the size of the atom or molecule is comparable to the wave length of light. If this condition is satisfied, the atom absorbs light and vibrates. Due to these vibrations, the atom re-emits a certain fraction of absorbed energy in all directions with different intensities. The re-emitted light is called scattered light and the process of re-emission of light in all directions with different intensity is called scattering of light. The atoms or molecules are called scattering centre. Let us take the angle ' $\theta$ ' between the incident light and a direction in which the intensity of scattered light is observed, we call this angle as angle of



scattering. It is experimentally observed that the intensity of scattered light varies with angle of scattering. The intensity is maximum at  $90^\circ$  angle of scattering.

This is the reason for the appearance of clear blue colour when look at the sky in a direction perpendicular to the direction of the sun rays. If our angle of view is changed, the intensity of blue colour also changes.

Now you might have got a doubt why scattering of light gives blue colour only. Why can't it give other colours?

Let us find out whether the scattering centres are responsible for the blue colour of the sky?

We know that our atmosphere contains different types of molecules and atoms. The reason for blue sky is due to the molecules  $N_2$  and  $O_2$ . The sizes of these molecules are comparable to the wavelength of blue light. These molecules act as scattering centres for scattering of blue light.

- Why is that the sky appears white sometimes when you view it in certain direction on hot days?

Our atmosphere contains atoms and molecules of different sizes. According to their sizes, they are able to scatter different wavelengths of light. For example, the size of the water molecule is greater than the size of the  $N_2$  or  $O_2$ . It acts as a scattering centre for other frequencies which are lower than the frequency of blue light.

On a hot day, due to rise in the temperature water vapour enters into atmosphere which leads to abundant presence of water molecules in the atmosphere. These water molecules scatter the colours of other frequencies (other than blue). All such colours of other frequencies reach your eye and the sky appears white.

- Can we demonstrate scattering of light by an experiment?

Let us try

### Activity 6

Take a solution of sodium-thio-sulphate (hypo) and sulphuric acid in a glass beaker. Place the beaker in an open place where abundant sun light is available. Watch the formation of grains of sulphur and observe changes in the beaker.

You will notice that sulphur precipitates as the reaction is in progress. At the beginning, the grains of sulphur are smaller in size and as the reaction progresses, their size increases due to precipitation.

Sulphur grains appear blue in colour at the beginning and slowly their colour becomes white as their size increases. The reason for this is

scattering of light. At the beginning, the size of grains is small and almost comparable to the wave length of blue light. Hence they appear blue in the beginning. As the size of grains increases, their size becomes comparable to wave lengths of other colours. As a result of this, they act as scattering centres for other colours. The combination of all these colours appears as white.

- Do you know the reasons for appearance the red colour of sun during sunrise and at sunset?

The atmosphere contains free molecules and atoms with different sizes. These molecules and atoms scatter light of different wavelengths which are comparable to their size. Molecules having a size that is comparable to the wavelength of red light are less in the atmosphere. Hence scattering of red light is less when compared to the other colours of light. The light from the sun needs to travel more distance in atmosphere during sunrise and sunset to reach your eye. In morning and evening times, during sunrise and sunset, except red light all colours scatter more and vanish before they reach you. Since scattering of red light is very small, it reaches you. As a result sun appears red in colour during sunrise and sunset.

- Can you guess the reason why sun does not appear red during noon hours?

During noon hours, the distance to be travelled by the sun rays in the atmosphere is less than that compared to morning and evening hours. Therefore all colours reach your eye without much scattering. Hence the sun appears white during noon hours.

### **?** Do you know?

Our beloved scientist and Noble prize winner, Sir C.V. Raman explained the phenomenon of light scattering in gases and liquids. He found experimentally that the frequency of scattered light by the liquids is greater than the frequency of incident light. This is called Raman Effect. By using this effect scientists determine the shapes of the molecules.



So far, we have learned some ideas of the light such as refraction, dispersion and scattering. These are wonderful phenomena occurring in our surroundings. When you observe any phenomena, try to resolve the problem and appreciate the wonderful world based on the behaviour of light.



## Key words

*Least distance of distinct vision, Angle of vision, Accommodation of eye lens, Myopia, Hypermetropia, Presbyopia, Power of lens, Prism, Angle of prism or refracting angle of prism, Angle of minimum deviation, Dispersion, Scattering.*



## What we have learnt

- The least distance of distinct vision is about 25cm and the angle of vision is about  $60^\circ$ .
- The ability of eye lens to change its focal length is called accommodation of lens.
- The defect in which people cannot see objects beyond far point is called **Myopia**.
- The defect in which people cannot see objects situated before near point is called **Hypermetropia**.
- **Presbyopia** is a vision defect indicating that the power of accommodation of the eye usually decreases with ageing.
- The reciprocal of focal length is called power of the lens.
- The refractive index of prism is given by
$$n = \frac{\sin[(A+D)/2]}{\sin(A/2)}$$
where A is angle of prism and D is angle of minimum deviation.
- The splitting of white light into colours (VIBGYOR) depending on the wave lengths is called dispersion.
- The process of re-emission of absorbed light in all directions with different intensities by atoms or molecules, is called scattering of light.



## Improve your learning

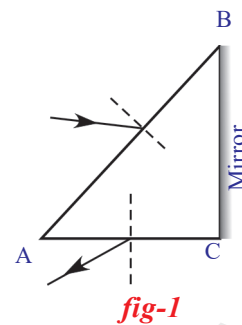
### Reflections on Concepts

1. How do you correct the eye defect Myopia? (AS<sub>1</sub>)
2. Explain the correction of the eye defect Hypermetropia. (AS<sub>1</sub>)
3. How do you find experimentally the refractive index of material of a prism? (AS<sub>3</sub>)
4. Explain the formation of rainbow. (AS<sub>1</sub>)
5. Explain two activities for the formation of artificial rainbow. (AS<sub>3</sub>)
6. Light of wavelength  $\lambda_1$  enters a medium with refractive index  $n_2$  from a medium with refractive index  $n_1$ . What is the wave length of light in second medium? (AS<sub>1</sub>)
7. Why does the sky sometimes appear white? (AS<sub>7</sub>)
8. A person is viewing an extended object. If a converging lens is placed in front of his eye, will he feel that the size of object has increased? Why? (AS<sub>7</sub>)



### Application of Concepts

- 1) Incident ray on one of the face (AB) of a prism and emergent ray from the face AC are given in figure -1. Complete the ray diagram. (AS<sub>5</sub>)
- 2) Glass is known to be a transparent material. But ground glass is opaque and white in colour. Why? (AS<sub>7</sub>)
- 3) A light ray falls on one of the faces of a prism at an angle  $40^\circ$  so that it suffers angle of minimum deviation of  $30^\circ$ . Find the angle of prism and angle of refraction at the given surface.

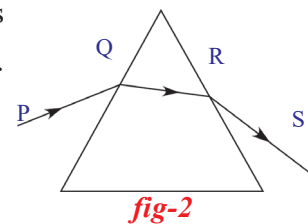


(Ans:  $50^\circ$ ,  $25^\circ$ ) (AS<sub>7</sub>)

- 4) The focal length of a lens suggested to a person with Hypermetropia is 100cm. Find the distance of near point and power of the lens. (Ans: 33.33cm, 1D) (AS<sub>7</sub>)

### Multiple choice questions

- 1) The size of an object as perceived by an eye depends primarily on [      ]  
 A) actual size of the object                      B) distance of the object from the eye  
 C) aperture of the pupil                              D) size of the image formed on the retina
- 2) When objects at different distances are seen by the eye which of the following remain constant?  
 A) focal length of eye-lens                      B) object distance from eye-lens [      ]  
 C) the radii of curvature of eye-lens              D) image distance from eye-lens
- 3) During refraction, \_\_\_\_\_ will not change. [      ]  
 A) Wave length    B) frequency    C) speed of light    D) all the above
- 4) A ray of light falls on one of the lateral surface of an equilateral glass prism placed on the horizontal surface of a table as shown in fig. 2. For minimum deviation of ray, which of the following is true?  
 [      ]



- A) PQ is horizontal                      B) QR is horizontal
- C) RS is horizontal                      D) either PQ or RS is horizontal

- 5) Far point of a person is 5m. In order that he has normal vision what kind of spectacles should he use [      ]  
 A) Concave lense with focal length 5m    B) concave lense with focal length 10m  
 C) Convex lense with focal length 5m    D) convex lense with focal length 2.5m

- 6) The process of re-emission of absorbed light in all directions with different intensities by the atom or molecule is called [      ]
- A) Scattering of light B) dispersion of light C) reflection of light D) refraction of light

### **Suggested Experiments**

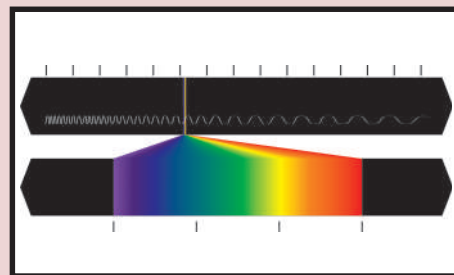
1. Conduct an experiment to produce a rainbow in your class room and explain the procedure. (AS<sub>3</sub>)
2. Conduct an experiment to find the refractive index of a prism.
3. Conduct an experiment to demonstrate the scattering of the light

### **Suggested Projects**

- 1) Prisms are used in binoculars. Collect information why prisms are used in binoculars. (AS<sub>4</sub>)
- 2) Collect the information about different types of eye defects from your nearest eye specialist or optical shop and write a report
- 3) Collect the different types of lenses used for correcting the eye defects and write a report.
- 4) Collect the information about the dispersion phenomenon occurs in the daily life.

## Chapter

# 6



# Structure of Atom

You have studied in the previous class about sub-atomic particles like negatively charged electrons, positively charged protons and electrically neutral neutrons.

- How do these sub-atomic particles coexist in an electrically neutral atom?

You have acquired some fundamental ideas about atomic models suggested by J J Thomson, Ernest Rutherford and Niels Bohr which have been presented in Class 9.

### Activity 1

On the basis of your previous knowledge you prepare a model of an atom.

- Can you arrange the sub-atomic particles in any other way in an atom? (Take the help of your friends, your teacher and the Internet). Observe your atomic model and the models of your friends carefully and try to answer the questions.
- Do all atoms have the same sub-atomic particles?
- Why is an atom of one element different from the atoms of other elements?
- How are the electrons distributed in of an atom?

To answer the above questions, we need to understand the nature of light, coloured flames and their characteristics.

## Spectrum

You must have observed the formation of a rainbow.

There are seven colours namely violet, indigo, blue, green, yellow, orange and red (VIBGYOR) in a rainbow.

You can find the colours spreading continuously and the intensity of each colour varies from one point to the other.

### Wave nature of light

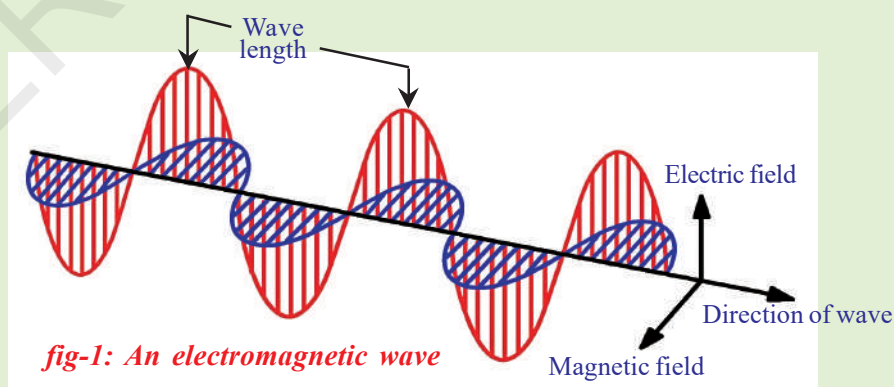
- When you throw a stone into a still pond, you observe ripples, which are transmitting the disturbance in the form of waves on the surface of water.
- You know that sound waves are produced when something vibrates; like a drum.
- In the same way electromagnetic waves are produced when an electric charge vibrates (moves back and forth).

A vibrating electric charge creates a change in the electric field. The changing electric field creates a changing magnetic field.

This process continuous, with both the created fields being perpendicular to each other and at right angles to the direction of propagation of the wave.

Visible light is an electromagnetic wave and the speed of light ( $c$ ) is  $3 \times 10^8 \text{ m s}^{-1}$ .

### Characteristics of electromagnetic wave



Electromagnetic energy travelling through a vacuum behaves in some way like ocean waves travelling through water. Like ocean waves, electromagnetic energy is characterized by wavelength ( $\lambda$ ), and frequency ( $\nu$ ).



The wavelength ( $\lambda$ ) of the wave is the distance from one wave peak to the next. The frequency ( $\nu$ ) of a wave is simply the number of wave peaks that pass by a given point per unit time, expressed in units of reciprocal seconds ( $1/s$  or  $s^{-1}$ ). The relation between these quantities is given by

$$\lambda \propto 1/\nu \quad \text{or} \quad c = \nu\lambda$$

It is a universal relationship and applies to all waves. As the frequency increases, the wavelength becomes smaller.

Electromagnetic waves can have a wide variety of frequencies. The entire range of electromagnetic wave frequencies is known as the *electromagnetic spectrum*.

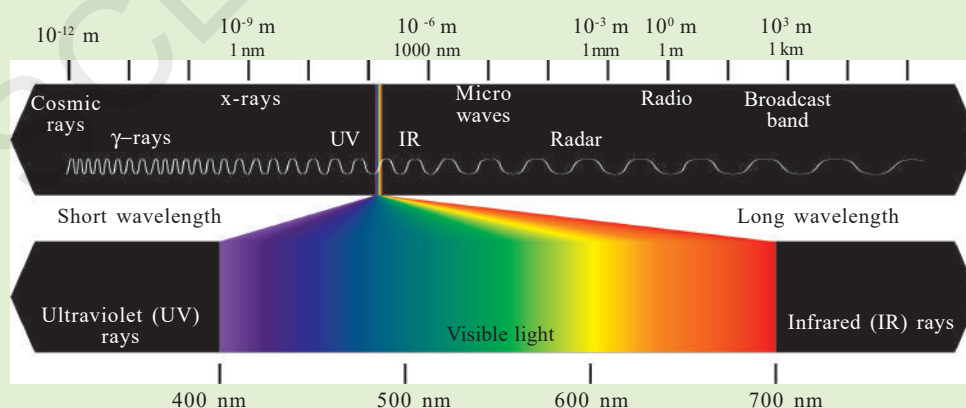
The familiar example of the visible spectrum in nature is the formation of a rainbow.

Each colour in a rainbow is characterized by a specified wavelength from red (higher wavelength) to violet (shorter wavelength). These colours (wavelengths), that the human naked eye is sensitive to, are called *visible light*. The range of wavelengths covering red colour to violet colour is called the *visible spectrum*.

## Electromagnetic spectrum

Electromagnetic waves can have a wide variety of wavelengths. The entire range of wavelengths is known as the electromagnetic spectrum.

The electromagnetic spectrum consists of a continuous range of wavelengths of gamma rays at the shorter wavelength to radio waves at the longer wavelength. But our eyes are sensitive only to visible light.



**fig-2: Electromagnetic Spectrum**

- What happens when you heat an iron rod on a flame?
- Do you find any change in colour on heating an iron rod?

When you heat an iron rod, some of the heat energy is emitted as light. First it turns red (lower energy corresponding to higher wavelength) and as the temperature rises it glows orange, yellow, blue (higher energy and of lower wavelength) or even white (all visible wavelengths) if the temperature is high enough.

- Do you observe any other colour at the same time when one colour is emitted?

When the temperature is high enough, other colours will also be emitted, but due to higher intensity of one particular emitted colour (e.g., red), others cannot be observed.

Max Planck broke with the ‘continuous energy’ tradition of electromagnetic energy by assuming that the energy is always emitted in multiples of  $h\nu$ ;

For example:  $h\nu$ ,  $2 h\nu$ ,  $3 h\nu$ ...  $nh\nu$

That is, the energy for a certain frequency  $E$  can be represented by the equation  $E = h\nu$ , where ‘ $h$ ’ is *Planck’s constant* which has the value  $6.626 \times 10^{-34} \text{Js}$  and ‘ $\nu$ ’ is the frequency of the radiation absorbed or emitted.

The energy ( $E$ ) for the red colour (higher wavelength or lower frequency) is lower compared to the energy of blue colour (lower wavelength or higher frequency). The energy emitted from a material body increases with increase in heat energy.

The significance of Planck’s proposal is that, *electromagnetic energy can be gained or lost in discrete values and not in a continuous manner.*

Hence, emission or absorption of light spectrum is a collection of a group of wavelengths.

- Do you enjoy Deepavali fireworks?  
Variety of colours is seen from fireworks.
- How do these colours come from fireworks?

### Activity 2

Take a pinch of cupric chloride in a watch glass and make a paste with concentrated hydrochloric acid. Take this paste on a platinum loop and introduce it into a non-luminous flame.

- What colour do you observe?

Carry out similar activity with strontium chloride.

Cupric chloride produces a green colour flame while strontium chloride produces a crimson red flame.

- Do you observe yellow light in street lamps?

Sodium vapours produce yellow light in street lamps.

- Why do different elements emit different flame colours when heated by the same non-luminous flame?

Scientists found that each element emits its own characteristic colour. These colours correspond to certain discrete wavelengths of light and are called *line spectra*.

The lines in atomic spectra can be used to identify unknown atoms, just like fingerprints are used to identify people.

### Bohr's model of hydrogen atom and its limitations

- What does a line spectrum tell us about the structure of an atom?

Niels Bohr proposed that *electrons in an atom occupy 'stationary' orbits (states) of fixed energy at different distances from the nucleus.*

When an electron 'jumps' from a lower energy state (ground state) to higher energy states (excited state) it absorbs energy or emits energy when such a jump occurs from a higher energy state to a lower energy state.

*The energies of an electron in an atom can have only certain values  $E_1, E_2, E_3, \dots$ ; that is, the energy is quantized. The states corresponding to these energies are called stationary states and the possible values of the energy are called energy levels.*

- The lowest energy state of the electron is known as ground state.
- What happens when an electron gains energy?

The electron moves to a higher energy level i.e. to the excited state.



**Niels Henrik David Bohr** was a Danish physicist who made foundational contributions to understanding atomic structure and quantum theory, for which he received the Nobel Prize in Physics in 1922. Bohr was also a philosopher and a promoter.



*fig-3: Hydrogen Spectrum*

- Does the electron retain the energy forever?

The electron loses the energy and comes back to its ground state. The energy emitted by the electron is seen in the form of electromagnetic energy and when the wavelength is in the visible region it is visible as an *emission line*.

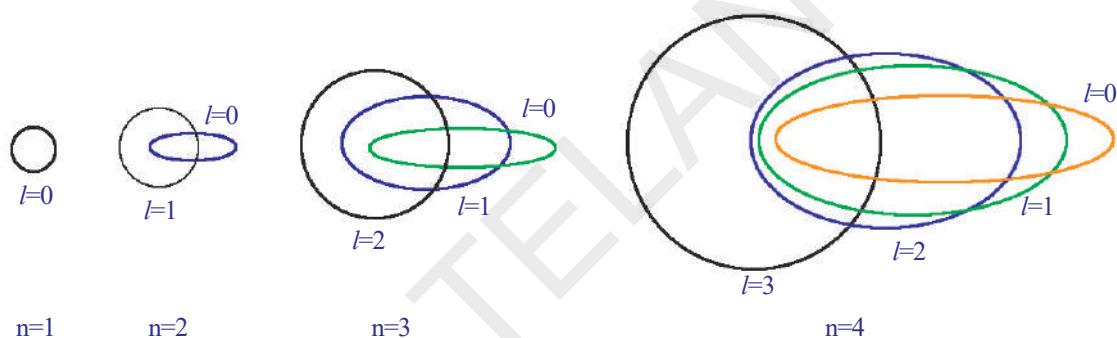
Bohr's model explains all the line spectra observed in the case of hydrogen atom. It is a successful model as far as line spectra of hydrogen atom is concerned.

But the line spectrum of hydrogen atom when observed through a high resolution spectroscopy appears as groups of finer lines.

- Did Bohr's model account for the splitting of line spectra of a hydrogen atom into finer lines?

Bohr's model failed to account for splitting of line spectra.

### Bohr-Sommerfeld model of an atom



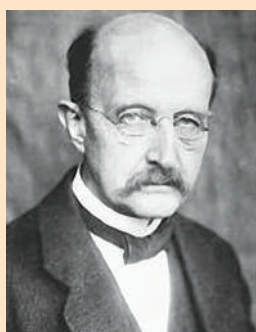
*fig-4: The allowed electronic orbits for the main Quantum numbers by Bohr - Sommerfeld model*

In an attempt to account for the structure (splitting) of line spectra known as fine spectra, Sommerfeld modified Bohr's atomic model by adding elliptical orbits. While retaining the first of Bohr's circular orbit as such, he added one elliptical orbit to Bohr's second orbit, two elliptical orbits to Bohr's third orbit, etc., such that the nucleus of the atom is one of the principal foci of these elliptical orbits. He was guided by the fact that, in general, periodic motion under the influence of a central force will lead to elliptical orbits with the force situated at one of the foci.

Bohr-Sommerfeld model, though successful in accounting for the fine line structure of hydrogen atomic spectra, does not provide a satisfactory picture of the structure of atom in general.

This model failed to account for the atomic spectra of atoms of more than one electron.

- Why is the electron in an atom restricted to revolve around the nucleus at certain fixed distances?



**Max Karl Ernst Ludwig Planck** was a German theoretical physicist who originated *quantum theory*, which won him the Nobel Prize in Physics in 1918. Planck made many contributions to theoretical physics, but his fame rests primarily on his role as originator of the *quantum theory*. This theory revolutionized human understanding of atomic and subatomic processes.

### Quantum mechanical model of an atom

- Do the electrons follow defined paths around the nucleus?

If the electron revolves around the nucleus in defined paths or orbits, the exact position of the electron at various times will be known. For that we have to answer two questions:

- What is the velocity of the electron?
- Is it possible to find the exact position of the electron?

Electrons are invisible to naked eye. Then, how do you find the position and velocity of an electron?

To find articles during dark nights we take the help of torchlight. Similarly, we can take the help of suitable light to find the position and velocity of electron. As the electrons are very small, light of very short wavelength is required for this task.

This short wavelength light interacts with the electron and disturbs the motion of the electron. Hence, simultaneously the position and velocity of electron cannot be measured accurately.

From the above discussion, it is clear that electrons do not follow definite paths in an atom.

Do atoms have a definite boundary, as suggested by Bohr's model?

If the electrons are not distributed in orbits around the nucleus this means that an atom does not have a definite boundary.

As a result, it is not possible to pinpoint an electron in an atom.

Under these circumstances in order to understand the properties of electrons in an atom, a quantum mechanical model of atom was developed by Erwin Schrodinger.

According to this model of an atom, instead of orbits of Bohr's model, the electrons are thought to exist in a particular region of space around the nucleus at a given instant of time

- What do we call the region of space where the electron might be, at a given time?

The region of space around the nucleus where the probability of finding the electron is maximum is called an orbital.

In a given space around the nucleus, only certain orbitals can exist. Each orbital of a stable energy state for the electron is described by a particular set of quantum numbers.

## Quantum numbers

Each electron in an atom is described by a set of three numbers  $n$ ,  $l$ , and  $m_l$ . These numbers are called **quantum numbers**. These numbers indicate the probability of finding the electron in the space around the nucleus.

- What information do the quantum numbers provide?

The quantum numbers describe the space around the nucleus where the electrons are found and also their energies. These are called atomic orbitals.

- What does each quantum number signify?

### 1. Principal Quantum Number ( $n$ )

The *principal* quantum number is related to the size and energy of the *main shell*.

' $n$ ' has positive integer values of 1, 2, 3, ...

As ' $n$ ' increases, the shells become larger and the electrons in those shells are farther from the nucleus.

An increase in ' $n$ ' also means higher energy.  $n = 1, 2, 3, \dots$  are often represented by the letters  $K, L, M, \dots$ . For each ' $n$ ' value there is one main shell.

Shell	K	L	M	N
$n$	1	2	3	4

### 2. The angular - momentum quantum number ( $l$ )

' $l$ ' has integer values from 0 to  $n-1$  for each value of ' $n$ '. Each ' $l$ ' value represents one sub-shell.

Each value of ' $l$ ' is related to the shape of a particular sub-shell in the space around the nucleus.

The value of ' $l$ ' for a particular sub-shell is generally designated by the letters  $s, p, d, \dots$  as follows:

$l$	0	1	2	3
Name of the sub-shell	s	p	d	f

When  $n = 1$ , there is only one sub-shell with  $l = 0$ . This is designated as '1s' orbital.

When  $n = 2$ , there are two sub-shells, with  $l = 0$ , the '2s' sub-shell and with  $l = 1$ , the '2p' sub-shell.

- What is the maximum value of 'l' for n=4?
- How many values can 'l' have for n = 4?

### 3. The magnetic quantum number ( $m_l$ )

The magnetic quantum number ( $m_l$ ) has integer values between  $-l$  and  $l$ , including zero. Thus for a certain value of  $l$ , there are  $(2l + 1)$  integer values of  $m_l$  as follows:

$$-l, (-l+1) \dots, -1, 0, 1, \dots (+l - 1), +l$$

These values describe the orientation of the orbital in space relative to the other orbitals in the atom.

When  $l=0$ ,  $(2l+1) = 1$  and there is only one value of  $m_l$ , thus we have only one orbital i.e., 1s.

When  $l=1$ ,  $(2l+1) = 3$ , that means  $m_l$  has three values, namely,  $-1, 0,$  and  $1$  or three  $p$  orbitals, with different orientations along  $x, y, z$  axes. These are labelled as  $p_x, p_y,$  and  $p_z$ .

- Do these three  $p$ -orbitals have the same energy?

The number of ' $m_l$ ' values indicates the number of orbitals in a sub-shell with a particular  $l$  value. Orbitals in the sub-shell belonging to the same shell possess same energy. These are called degenerated orbitals.

Fill the table-1 with the number of degenerated orbitals per sub-shell using  $(2l+1)$  rule. **s**-orbital is spherical in shape, **p**-orbital is dumbbell-shaped and **d**-orbital are double dumbbell-shaped as shown below.

Table-1

$l$	Sub-shell	Number of degenerated orbitals
0	s	
1	p	
2	d	
3	f	

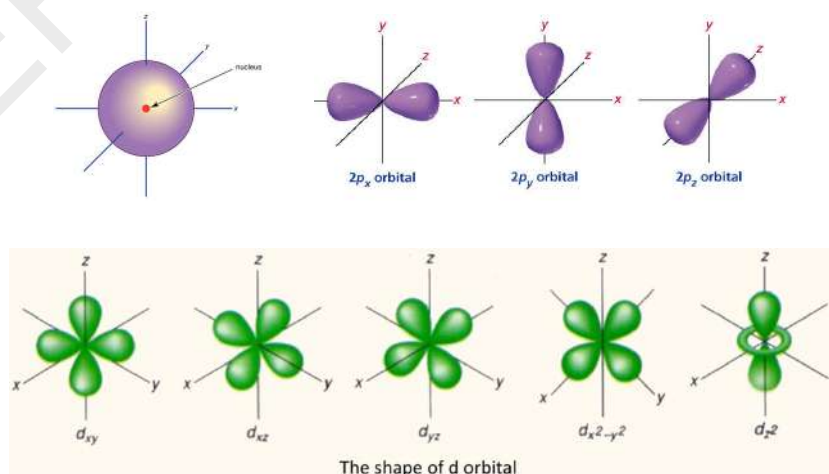


fig-5: Shapes of orbitals in s, p and d subshells

The following table-2 represents the shells, sub-shells and the number of orbitals in the sub-shells.

**Table-2**

n	<i>l</i>	$m_l$	sub-shell notation	No of orbitals in the subshell
1	0	0	1s	1
2	0	0	2s	1
	1	-1,0,+1	2p	3
3	0	0	3s	1
	1	-1,0,+1	3p	3
	2	-2,-1,0,+1,+2	3d	5
4	0	0	4s	1
	1	-1,0,+1	4p	3
	2	-2,-1,0,+1,+2	4d	5
	3	-3,-2,-1,0,+1,+2,+3	4f	7

**Table-3**

Sub shells	Number of orbitals ( $2l+1$ )	Maximum number of electrons
s ( $l=0$ )	1	2
p ( $l=1$ )	3	6
d ( $l=2$ )	5	10
f ( $l=3$ )	7	14

Each sub-shell holds a maximum of twice as many electrons as the number of orbitals in the sub-shell.

The maximum number of electrons that can occupy various sub-shells is given in the following table.

#### 4. Spin Quantum Number ( $m_s$ )

The three quantum numbers  $n$ ,  $l$ , and  $m_l$  describe the size (energy), shape, and orientation, respectively, of an atomic orbital in space.

As you have observed in the case of street lights (sodium vapour lamp), yellow light is emitted. This yellow light is comprised of a very closely spaced doublet when analyzed using high resolution spectroscope.

Alkali and alkaline earth metals show such type of lines.

To account for such a behavior of electron an additional quantum number is introduced. This is spin quantum number. This represents the property of the electron. It is denoted by ' $m_s$ '.



This quantum number refers to the two possible orientations of the spin of an electron, one clockwise and the other anticlockwise spin. These are represented by  $+\frac{1}{2}$  and  $-\frac{1}{2}$ . If both are positive values, then the spins are parallel otherwise the spins are anti-parallel.

The importance of the spin quantum number is seen when electrons occupy specific orbitals in multi-electron atoms.

- How do electrons in an atom occupy shells, sub-shells and orbitals?

The distribution of electrons in shells, sub-shells and orbital in an atom is known as *electronic configuration*.

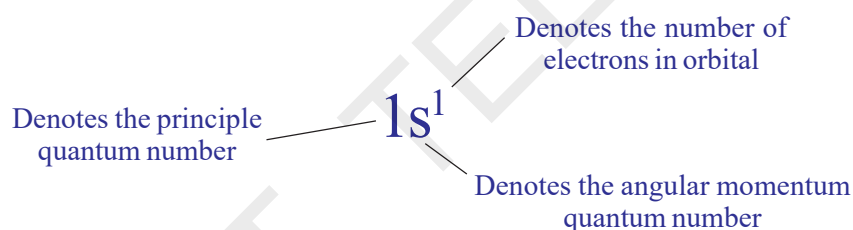
## Electronic Configuration

Let us first consider the hydrogen atom for understanding the arrangement of electrons, as it contains only one electron.

The shorthand notation consists of the principal energy level ( $n$  value), the letter representing sub-level ( $l$  value), and the number of electrons ( $x$ ) in the sub-shell is written as a superscript as shown below:

$$nl^x$$

For the hydrogen (H) atom having atomic number ( $Z$ ) = 1, the number of electrons is one, then the electronic configuration is  $1s^1$ .



The electron configuration can also be represented by showing the spin of the electron.

For the electron in H, as you have seen, the set of quantum numbers is:

$$n = 1, l = 0, m_l = 0, m_s = \frac{1}{2} \text{ or } -\frac{1}{2}.$$



For many-electron atoms, we must know the electron configuration of the atom. The distribution of electrons in various atomic orbitals provides an understanding of the electronic behavior of the atom and, in turn, its reactivity. Let us consider the helium (He) atom.

- Helium ( $Z=2$ ) atom has two electrons.
- How are these two electrons arranged?

To describe the electronic configuration for more than one electron in the atom, we need to know three principles:

Those are the *Pauli Exclusion Principle*, *Aufbau principle* and *Hund's Rule*.

Let us discuss them briefly.

## The Pauli Exclusion Principle

Helium atom has two electrons. The first electron occupies '1s' orbital. The second electron joins the first in the 1s-orbital, so the electron configuration of the ground state of 'He' is  $1s^2$ .

- Then the question is: What are the spins of these two electrons?

According to Pauli Exclusion Principle no two electrons of the same atom can have all four quantum numbers the same.

If  $n$ ,  $l$ , and  $m_l$  are same for two electrons then  $m_s$  must be different. In the helium atom the spins must be paired.

Electrons with paired spins are denoted by ' $\uparrow\downarrow$ '. One electron has

$m_s = +\frac{1}{2}$ , the other has  $m_s = -\frac{1}{2}$ . They have anti-parallel spins.

- How many electrons can occupy an orbital?

The major consequence of the exclusion principle involves orbital occupancy. Since only two values of  $m_s$  are allowed, an orbital can hold only two electrons and they must have opposite spins.

Hence, the electronic configuration of helium atom is:



## Aufbau Principle

As we pass from one element to another one of next higher atomic number, one electron is added every time to the atom.

The maximum number of electrons in any shell is ' $2n^2$ ', where ' $n$ ' is the principal quantum number.

The maximum number of electrons in a sub-shell (s, p, d or f) is equal to  $2(2l+1)$  where  $l = 0, 1, 2, 3, \dots$ . Thus these sub-shells can have a maximum of 2, 6, 10, and 14 electrons respectively.

In the ground state the electronic configuration can be built up by placing electrons in the lowest available orbitals until the total number of electrons added is equal to the atomic number. This is called the Aufbau principle (The German word "Aufbau" means "building up."). Thus orbitals are filled in the order of increasing energy.

Two general rules help us to predict electronic configurations.

1. Electrons are assigned to orbitals in order of increasing value of  $(n+l)$ .
2. For sub-shells with the same value of  $(n+l)$ , electrons are assigned first to the sub-shell with lower ' $n$ '.

The following diagram shows the increasing value of  $(n+l)$ . Ascending order of energies of various atomic orbitals is given below.

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

The electronic configuration of some elements in the increasing atomic number ( $Z$ ) value is given below.

H( $Z=1$ )	$1s^1$	$\uparrow$				
He( $Z=2$ )	$1s^2$	$\uparrow\downarrow$				
Li( $Z=3$ )	$1s^2 2s^1$	$\uparrow\downarrow$	$\uparrow$			
Be( $Z=4$ )	$1s^2 2s^2$	$\uparrow\downarrow$	$\uparrow\downarrow$			
B( $Z=5$ )	$1s^2 2s^2 2p^1$	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow$		

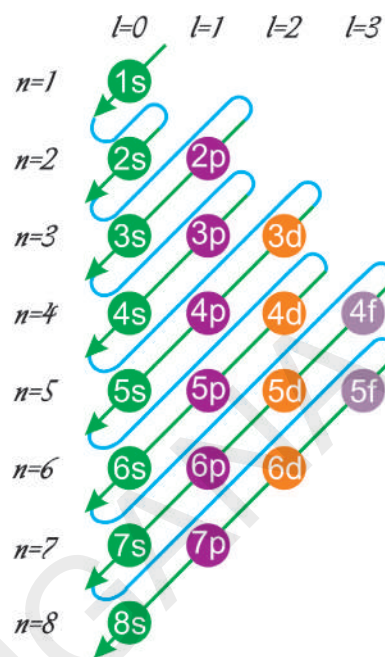


fig-6: The filling order of atomic orbitals (Moeller Chart)

- For carbon (C) atom ( $Z=6$ ), where does the 6<sup>th</sup> electron go?
- Whether the electron pairs up in the same  $p$ -orbital or will it go to the next  $p$ -orbital?

### Hund's Rule

According to this rule electron pairing in orbitals starts only when all available empty orbitals of the same energy (*degenerate orbitals*) are singly occupied.

The configuration of Carbon (C) atom ( $Z=6$ ) is  $1s^2 2s^2 2p^2$ . The first four electrons go into the  $1s$  and  $2s$  orbitals. The next two electrons go into separate  $2p$  orbitals, with both electrons having the same spin



Note that the unpaired electrons in the  $2p$  orbitals are shown with parallel spins.

### Activity 3

Complete the electronic configuration of the following elements.

Table.4

Element	Atomic number (Z)	Electronic configuration of elements
C	6	
N	7	
O	8	
F	9	
Ne	10	
Na	11	
Mg	12	
Al	13	
Si	14	
P	15	
S	16	
Cl	17	
Ar	18	
K	19	
Ca	20	



#### Key words

*Wave, spectrum, intensity, discrete energy, line spectrum, orbital, quantum numbers, shell, sub-shell, shapes of orbitals electron spin, electronic configuration, the Pauli's exclusion principle, Aufbau principle, Hund's rule.*



#### What we have learnt

- Light can be characterized by its *wavelength* ( $\lambda$ ) and frequency ( $\nu$ ), and these quantities are related to the speed of light ( $c$ ) as:  $c = \nu\lambda$ .
- Spectrum is a group of wavelengths.
- Electromagnetic energy (Light) can have only certain discrete energy values which is given by the equation  $E=h\nu$
- Electrons in an atom can gain energy by absorbing a particular frequency of light and can lose energy by emitting a particular frequency.

- Bohr's model of atom: Electrons are present in stationary states. The electron moves to higher energy level if it absorbs energy in the form of electromagnetic energy or moves to a lower energy state by emitting energy in the form of electromagnetic energy of appropriate frequency.
- Atomic line spectra arise because of absorption /emission of certain frequencies of light energy.
- It is not possible to measure accurately the position and velocity of an electron simultaneously.
- The space around the nucleus where the probability of finding the electron is maximum is called orbital.
- The three quantum numbers  $n, l, m_l$  describe the energy, shape and orientation respectively, of an atomic orbital.
- Spin is an intrinsic property of an electron.
- The arrangement of electrons in shells, sub-shells and orbitals in an atom is called the electron configuration.
- According to Pauli Exclusion Principle no two electrons of the same atom can have all the four quantum numbers same.
- Aufbau principle: The lowest-energy orbitals are filled first.
- Hund's rule: The orbitals of equal energy (degenerate) are occupied with one electron each before pairing of electrons starts.



### Improve your learning



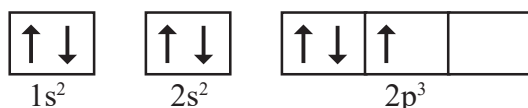
#### Reflections of concepts

1. What information does the electronic configuration of an atom provide? (AS<sub>1</sub>)
2. Rainbow is an example for continuous spectrum – explain. (AS<sub>1</sub>)
3. How orbital is different from Bohr's orbit?(AS<sub>1</sub>)
4. Explain the significance of three Quantum numbers in predicting the positions of an electron in an atom.(AS<sub>1</sub>)
5. How we are using the  $n/l^x$  method in writing electronic configuration? (AS<sub>1</sub>)
6. Which electronic shell is a higher energy level K or L? (AS<sub>2</sub>)

#### Application of concepts

1. Answer the following questions.
  - a. How many maximum number of electrons can be accommodated in a principal energy level?
  - b. How many maximum number of electrons can be accommodated in a sub shell?
  - c. How many maximum number of electrons can be accommodated in an orbital?
  - d. How many sub shells are present in a principal energy level?
  - e. How many spin orientations are possible for an electron in an orbital? (AS<sub>1</sub>)

2. In an atom the number electrons in M-shell is equal to the number of electrons in the K and L Shell. Answer the following questions. (AS<sub>4</sub>)
- Which is the outer most shell?
  - How many electrons are there in its outermost shell?
  - What is the atomic number of element?
  - Write the electronic configuration of the element.
3. Following orbital diagram shows the electron configuration of nitrogen atom. Which rule does not support this? N (Z = 7) (AS<sub>1</sub>)



4. Write the four quantum numbers for the differentiating electron of sodium (Na) atom? (AS<sub>1</sub>)
5. (i) An electron in an atom has the following set of four quantum numbers to which orbital does it belong

n	l	m <sub>l</sub>	m <sub>s</sub>
2	0	0	+ 1/2

- (ii) Write the four quantum numbers for 1s<sup>1</sup> electron. (AS<sub>4</sub>)
6. The wave length of a radio wave is 1.0m. Find its frequency. (AS<sub>7</sub>)

### Multiple choice questions

- An emission spectrum consists of bright spectral lines on a dark back ground. Which one of the following does not correspond to the bright spectral lines? [      ]  
 A) Frequency of emitted radiation      B) Wave length of emitted radiation  
 C) Energy of emitted radiations      D) Velocity of light
- The maximum number of electrons that can be accommodated in the L – shell of an atom is  
 A) 2      B) 4      C) 8      D) 16      [      ]
- If l = 1 for an atom then the number of orbitals in its sub-shell is [      ]  
 A) 1      B) 2      C) 3      D) 0
- The quantum number which explains about size and energy of the orbit or shell is: [      ]  
 A) n      B) l      C) m<sub>l</sub>      D) m<sub>s</sub>

### Suggested Projects

- Collect the information of historical development of the atomic theory.
- Collect the information about the scientists who developed the atomic theories.
- Make the s, p and d orbital models.
- Collect the information regarding wave lengths and corresponding frequencies of three primary colours red, blue and green.

## Chapter

# 7



# Classification of Elements- The Periodic Table

A medical shop contains a vast number of medicines. The shop keeper finds it difficult to remember all the names of medicines that he has. When you go to a medical shop and ask the shopkeeper for a particular medicine, he hands over it to you without any difficulty. How is it?

Think of a super bazaar. When you step in to it you see a particular arrangement of goods inside it. When you look for needed grocery, you can select it easily.

From the above observations you understand that for any system involving several things, a particular order of arrangement of those things is essential.

Even in chemistry, from the earliest times, scientists have been trying to classify the available elements in to a limited number of groups on the basis of their properties.

### Need for the arrangement of elements in an organised manner

Robert Boyle (1661) defined an element as any substance that cannot be decomposed into a further simple substance by a physical or chemical change.

At his time, about thirteen elements were known.

Towards the end of the eighteenth century, by the time of Lavoisier another eleven elements were discovered. By 1865 about sixty three elements were known and by 1940, a total of ninety one elements from natural sources and another seventeen elements synthetically were obtained.

By now, including synthetic elements, there are more than 118 elements. As the number of elements increased, it became difficult to keep in memory the chemistries of individual elements and their compounds.

In previous classes we had learnt the classifications of elements in metals and non-metals. For example sodium, potassium, etc. are metals and sulphur, chlorine are non-metals. But this classification had so many limitations Aluminium has some metallic properties and some non-metallic properties. Elements of this type are considered as metalloids or semi metals. So, there was a need to classify them in still better ways. Hence, chemists started to frame ways to group the elements and compounds on the basis of their physical and chemical properties.

In the beginning of the 18<sup>th</sup> century Joseph Louis Proust stated that hydrogen atom is the building material and atoms of all other elements are simply due to the combination of number of hydrogen atoms. (It is to be noted that at his time the atomic weights of all elements were given as whole numbers and the atomic weight of hydrogen was taken as one.)

### Dobereiner's law of Triads

A German chemist Johann Wolfgang Döbereiner (1829) noted that there were groups of elements with three elements known as *triads* in each group with similar chemical properties. He tried to give a relationship between the properties of elements and their atomic weights.

Döbereiner stated that when elements with similar properties are taken three at a time and arranged in the ascending order of their atomic weights, the atomic weight of the middle element is the average of the atomic weights of the first and third elements. This statement is called the Dobereiner's *law of triads*.

### Activity 1

Observe the following table.

Elements in each row represent a triad.

Group	Elements and their Atomic weights			Arithmetic mean of Atomic weight
A	Lithium (Li) 7.0	Sodium (Na) 23.0	Potassium (K) 39.0	$\frac{7.0 + 39.0}{2} = 23.0$
B	Calcium (Ca) 40.0	Strontium (Sr) 88	Barium (Ba) 137.0	
C	Chlorine (Cl) 35.5	Bromine (Br) 80.0	Iodine (I) 127.0	
D	Sulphur (S) 32.0	Selenium (Se) 78.0	Tellurium (Te) 125.0	
E	Manganese (Mn) 55.0	Chromium (Cr) 52.0	Iron (Fe) 56.0	



In the first row you will find that atomic weight of sodium (Na) is equal to the average of atomic weights of Li and K.

- Can you establish the same relationship with the set of elements given in the remaining rows?
- Find average atomic weights of the first and third elements in each row and compare it with the atomic weight of the middle element.
- What do you observe?



**Döbereiner**

Döbereiner's attempts gave a clue that atomic weights could be correlated with properties of elements. It made chemists look at elements in terms of groups of elements with similar chemical and physical properties. This eventually led to rigorous classification of elements and to develop modern periodic table of elements.

### Limitations

- i. All the known elements at that time could not be arranged in the form of triads.
- ii. The law failed for very low mass or for very high mass elements.

In case of F, Cl, Br, the atomic weight of Cl is not an arithmetic mean of atomic weights of F and Br.

- iii. As the techniques improved for measuring atomic masses accurately, the law was unable to remain strictly valid.



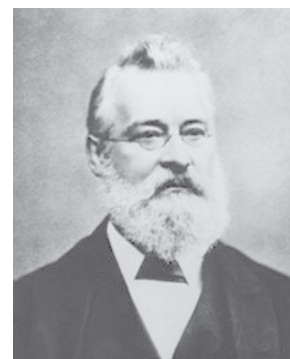
### Think and discuss

- What relation about elements did Döbereiner want to establish?
- The densities of calcium (Ca) and barium (Ba) are 1.55 and 3.51  $\text{g cm}^{-3}$  respectively. Based on Döbereiner's law of triads can you give the approximate density of strontium (Sr)?

### Newlands' law of Octaves

John Newlands was a British chemist. Newlands (1865) found that when elements were arranged in the ascending order of their atomic weights they appeared to fall into seven groups. Each group contained elements with similar chemical properties. Based on these observations, Newlands proposed the law of octaves.

*The law of octaves* states that when elements are arranged in the ascending order of their atomic weights they fall into a pattern in which their properties repeat at regular intervals. Every eighth



**Newlands**

element starting from a given element resembles in its properties to that of the given element. Elements with similar chemical properties are to be present along a horizontal row.

**Table 1: Newlands' table of elements (1866).**

Element No.	Element No.	Element No.	Element No.	Element No.	Element No.	Element No.	Element No.	Element No.	Element No.
H 1	F 8	Cl 15	Co&Ni 22	Br 29	Pd 36	I 42	Pt&Ir 50		
Li 2	Na 9	K 16	Cu 23	Rb 30	Ag 37	Cs 44	Os 51		
G 3	Mg 10	Ca 17	Zn 24	Sr 31	Cd 38	Ba&V 45	Hg 52		
Bo 4	Al 11	Cr 19	Y 25	Ce&La 33	U 40	Ta 46	Tl 53		
C 5	Si 12	Ti 18	In 26	Zr 32	Sn 39	W 47	Pb 54		
N 6	P 13	Mn 20	As 27	Di&Mo 34	Sb 41	Nb 48	Bi 55		
O 7	S 14	Fe 21	Se 28	Ro&Ru 35	Te 43	Au 49	Th 56		

Newlands was the first to assign numbers to the elements. Unfortunately his work was neither accepted by his seniors nor by the Journal of the Chemical Society, which rejected its publication.

In Newlands' table of elements, if we start with hydrogen and move down to oxygen and then start at the top the eighth element from hydrogen is fluorine and next eighth element is chlorine and so on. The properties of hydrogen, fluorine and chlorine are similar.

Similarly, if you start at lithium, then eighth element is sodium and next coming eighth is potassium and so on. These elements show similar physical and chemical properties for example they are reactive metals.



### Think and discuss

- Do you know why Newlands proposed the law of octaves? Explain your answer in terms of the modern structure of the atom.
- Do you think that Newlands' law of octaves is correct? Justify

Newlands' table is not without problems.

- There are instances of two elements fitted into the same slot, e.g. cobalt and nickel.
- Certain elements, totally dissimilar in their properties, were fitted into the same group.

For example he arranged Co, Ni, Pd, Pt and Ir which have different properties compared with halogens in the same row (F, Cl, Br, I). (see Newlands' first horizontal row)

Newlands periodic table was restricted to only 56 elements and did not leave any room for new elements. Elements that were discovered later could not be fitted into Newlands table in accordance with their properties.

Newlands attempted to link the periodicity of the chemical properties of elements with the periodicity found in the music. In musical scale any note in a key is separated from its octave by an interval of seven notes. This must have made him to force to arrange all the elements into this active pattern sometimes without caring the similarities.

### **(?) Do you know?**

Are you familiar with musical notes?

In the Indian system of music, there are seven musical notes in a scale – *sa, re ga, ma, pa, da, ni*. In the west, they use the notations - *do, re, mi, fa, so, la, ti*. Naturally, there must be some repetition of notes. Every eighth note is similar to the first one and it is the first note of the next scale.

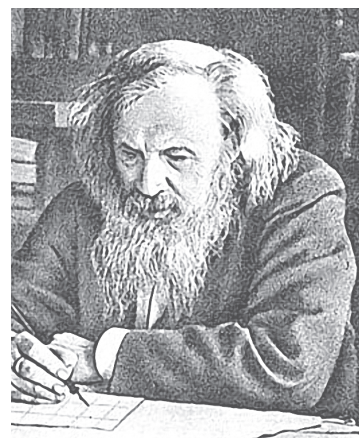
### **Mendeleeff's Periodic Table**

Mendeleeff arranged the elements known at that time in a chart in a systematic order in the increasing order of their atomic weights refer to table 2 the modified Mendeleeff's periodic table 2a. He divided the chart into 8 vertical columns known as *groups*. Each group is divided into A, B sub groups. Each column contained the elements of similar chemical properties. It is said that elements in a group have similar properties and elements along periods (horizontal rows) have different properties.

The elements in the first column, for example, react with oxygen to form compounds with the general formula  $R_2O$ . For example, Li, Na and K when react with oxygen and form compounds  $Li_2O$ ,  $Na_2O$  and  $K_2O$  respectively.

Elements of the second column react with oxygen to form compounds with the general formula  $RO$ . For example, Be, Mg and Ca when react with oxygen form  $BeO$ ,  $MgO$  and  $CaO$ .

Mendeleeff tried to explain the similarities of elements in the same group in terms of their common valency.



**Mendeleeff**

## The Periodic Law

Based on Mendeleeff's observations regarding the properties of elements in the periodic table, a law known as the *periodic law* of the properties of elements was proposed as follows.

*"The law states that the physical and chemical properties of the elements are periodic functions of their atomic weights."*

**Table-2(a) : Mendeleeff's Periodic Table (1871 version)**

Reihen	Gruppe I. — R <sup>2</sup> O	Gruppe II. — RO	Gruppe III. — R <sup>2</sup> O <sup>3</sup>	Gruppe IV. RH <sup>4</sup> RO <sup>2</sup>	Gruppe V. RH <sup>3</sup> R <sup>2</sup> O <sup>5</sup>	Gruppe VI. RH <sup>2</sup> RO <sup>3</sup>	Gruppe VII. RH R <sup>2</sup> O <sup>7</sup>	Gruppe VIII. — RO <sup>4</sup>
1	H = 1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fo=56, Co=59 Ni=59, Cu=63
5	(Cu=63)	Zn=65	—=68	—=72	As=75	So=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104 Pd=106, Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	I=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	—
10	—	—	?Ek=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199
11	(Au=198)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	—
12	—	—	—	Th=231	—	U=240	—	— — — —

**Table-2(b) : Modified Mendeleeff's Periodic Table Of Elements**

PERIODS	SERIES	GROUPS OF ELEMENTS																	
		I		II		III		IV		V		VI		VII		VIII		0	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B				
I	1.	1. H Hydrogen 1.008												1. H Hydrogen 1.008					
II	2.	3. Li Lithium 6.940	4. Be Beryllium 9.013	5. B Boron 10.82	6. C Carbon 12.011	7. N Nitrogen 14.008	8. O Oxygen 16	9. F Fluorine 19.00	10. Ne Neon 20.183										
III	3.	11. Na Sodium (Natrium) 22.991	12. Mg Magnesium 24.32	13. Al Aluminium 26.98	14. Si Silicon 28.09	15. P Phosphorus 30.975	16. S Sulphur 32.006	17. Cl Chlorine 35.457	18. Ar Argon 39.944										
IV	4.	19. K Potassium (Kalium) 39.100	20. Ca Calcium 40.08	21. Sc Scandium 44.96	22. Ti Titanium 47.90	23. V Vanadium 50.95	24. Cr Chromium 52.01	25. Mn Manganese 54.94	26. Fe Iron (Ferrum) 55.85	27. Co Cobalt 58.94	28. Ni Nickel 58.96	29. Cu Copper 63.54	30. Zn Zinc 65.38	31. Ga Gallium 69.7	32. Ge Germanium 72.60	33. As Arsenic 74.91	34. Se Selenium 78.96	35. Br Bromine 79.916	36. Kr Krypton
V	6.	37. Rb Rubidium 85.48	38. Sr Strontium 87.63	39. Y Yttrium 88.92	40. Zr Zirconium 91.22	41. Nb Niobium 92.91	42. Mo Molybdenum 95.95	43. Tc Technetium 99	44. Ru Ruthenium 101.1	45. Rh Rhodium 102.91	46. Pd Palladium 106.7	47. Ag Silver (Argentum) 107.880	48. Cd Cadmium 112.41	49. In Indium 114.76	50. Sn Tin (Stannum) 118.70	51. Sb Antimony (Stibium) 121.76	52. Te Tellurium 127.61	53. I Iodine 126.91	54. Xe Xenon 131.3
VI	8.	55. Cs Cesium 132.91	56. Ba Barium 137.36	57. La* Lanthanum 138.92	72. Hf Hafnium 178.6	73. Ta Tantalum 180.95	74. W Tungsten (Wolfram) 183.92	75. Re Rhenium 186.31	76. Os Osmium 190.2	77. Ir Iridium 192.2	78. Pt Platinum 195.23	79. Au Gold (Aurum) 197.0	80. Hg Mercury (Hydrargyrum) 200.61	81. Tl Thallium 204.39	82. Pb Lead (Plumbum) 207.21	83. Bi Bismuth 209.00	84. Po Polonium 210	85. At Astatine 210	86. Rn Radon 222
VII	10.	87. Fr Francium 233	88. Ra Radium 226.05	89. Ac** Actinium 227	104. Ku Kurchatovium 257	105. Ha Hassium 260													
* Lanthanoid Series																			
		58. Ce Cerium 140.13	59. Pr Praseo- dymium 140.92	60. Nd Neody- mium 144.27	61. Pm Prometh- ium 145	62. Sm Samarium 150.43	63. Eu Europium 152	64. Gd Gadolinium 156.9	65. Tb Terbium 158.93	66. Dy Dysprosium 162.46	67. Ho Holmium 164.94	68. Er Erbium 167.2	69. Tm Thulium 168.94	70. Yb Ytterbium 173.04	71. Lu Lutetium 174.99				
** Actinoid Series																			
		90. Th Thorium 232.05	91. Pa Protac- tinium 231	92. U Uranium 238.07	93. Np Neptunium 237	94. Pu Plutonium 242	95. Am Americium 243	96. Cm Curium 245	97. Bk Berkelium 245	98. Cf Californium 248	99. Es Einsteinium 253	100. Fm Fermium 255	101. Md Mendelevium 256	102. No Nobelium 254	103. Lr Lawrencium 257				

## Salient features and achievements of the Mendeleeff's periodic table

- 1. Groups and sub-groups:** There are eight vertical columns in Mendeleeff's periodic table called *groups*. They are represented by Roman numerals I to VIII. Elements present in a given vertical column (group) have similar properties. Each group is divided into two sub-groups 'A' and 'B'. The elements within any sub-group resemble one another to a greater extent. For example, sub-group IA elements called 'alkali metals' (Li, Na, K, Rb, Cs) resemble each other very much in their properties.
- 2. Periods:** The horizontal rows in Mendeleeff's periodic table are called *periods*. There are seven periods in the table, which are denoted by Arabic numerals 1 to 7. Elements in a period differ in their properties from one another. A period comprises the entire range of elements after which properties repeat themselves.
- 3. Predicting the properties of missing elements:** Based on the arrangement of the elements in the table he predicted that some elements were missing and left blank spaces at the appropriate places in the table.

Mendeleeff believed that some new elements would be discovered definitely. He predicted the properties of these new additional elements in advance entirely depending on his table. His predicted properties were almost the same as the observed properties of those elements after their discovery.

He named those predicted elements tentatively by adding the prefix '*eka*' (*eka* is a Sanskrit word for numeral one) to the name of the element immediately above each empty space. The predicted properties of elements namely eka-boron, eka-aluminium and eka-silicon were almost same as those of scandium, gallium and germanium respectively which were discovered later.

**Table-3**

S. No.	Property	Predicted property by Mendeleeff		Observed property	
		Eka-Aluminium (Ea)	Eka-Silicon (Es)	Gallium (1875)	Germanium (1886)
1	Atomic weight	68	72	69.72	72.59
2	Density	5.9	5..5	5.94	5.47
3	Formula of oxide	Ea <sub>2</sub> O <sub>3</sub>	EsO <sub>2</sub>	Ga <sub>2</sub> O <sub>3</sub>	GeO <sub>2</sub>
4	Formula of chloride	EaCl <sub>3</sub>	EsCl <sub>4</sub>	GaCl <sub>3</sub>	GeCl <sub>4</sub>

### **(?) Do you know?**

Do you know what Mendeleeff said about the melting point of *eka Al*?  
'If I hold it in my hand, it will melt'. The melting point of Ga is 30.2°C and our body temperature 37°C.

- 4. Correction of atomic weights:** The placement of elements in Mendeleeff's periodic table helped in correcting the atomic masses of some elements like, beryllium, indium and gold.

For example, at the time of Mendeleeff, beryllium (Be) was given atomic weight 13.5.

Atomic weight = equivalent weight  $\times$  valency

The equivalent weight of Be was found experimentally as 4.5 and its valency was thought as 3. Therefore, the atomic weight of beryllium was given at that time as  $4.5 \times 3 = 13.5$ . With this atomic weight it had to be placed in a wrong group in the table. He said that its valency should be only 2. Then its atomic weight would be  $4.5 \times 2 = 9$ . If atomic weight of 'Be' is 9 it would be fit in the second group and its properties practically are similar to Mg, Ca etc., of the second group elements. He also helped in the calculation of the correct atomic weights of 'Indium' and 'Gold' in this manner.

- 5. Anomalous series:** Some anomalous series of elements like 'Te' and 'I' were observed in the table. The anomalous series contained elements with more atomic weights like 'Te' (127.6 U) placed before the elements with less atomic weights like 'I' (126.9 U). Mendeleeff accepted minor inversions in the order of increasing atomic weights as these inversions resulted in elements being placed in the correct groups.

It was the extraordinary thinking of Mendeleeff that made the chemists to accept the periodic table and recognise Mendeleeff more than anyone else as the originator of the periodic law.

### **(?) Do you know?**

At the time when Mendeleeff introduced his periodic table even electrons were not discovered. Even then the periodic table was able to provide a scientific base for the study of chemistry of elements. In his honour the 101<sup>th</sup> element was named *Mendelevium*.

## Limitations of Mendeleeff's periodic table

- 1. Anomalous pair of elements:** Certain elements of highest atomic weights precede those with lower atomic weights.  
For example, *tellurium* (atomic weight 127.6) precedes *iodine* (atomic weight 126.9).
- 2. Dissimilar elements placed together:** elements with dissimilar properties were placed in same group as sub-group A and sub-group B.  
For example, alkali metal like Li, Na, K etc., of IA group have little resemblance with coinage metals like Cu, Ag, Au of IB group. *Cl* is of VII A group and 'Mn' is of VII B, but chlorine is a non metal, where as manganese is a metal.



### Think and discuss

- Why Mendeleeff had to leave certain blank spaces in his periodic table? What is your explanation for this?
- What is your understanding about  $Ea_2O_3$ ,  $EsO_2$ ?



### Think and discuss

- All alkali metals are solids but hydrogen is a gas with diatomic molecules. Do you justify the inclusion of hydrogen in first group with alkali metals?

## Modern Periodic Table

H.J. Moseley (1913) found that each element emits a characteristic pattern of X-rays when subjected to bombardment with high energy electrons. By analyzing the X-ray patterns, Moseley was able to calculate the number of positive charges in the atoms of respective elements. The number of positive charges (protons) in the atom of an element is called the atomic number of the element. With this analysis Moseley realised that the atomic number ( $Z$ ) is more fundamental characteristic of an element than its atomic weight.

After knowing the atomic numbers of elements, it was recognized that a better way of arranging the elements in the periodic table is according to the increasing atomic number.

This arrangement eliminated the problem of anomalous series. For example, though tellurium (Te) has more atomic weight than iodine (I), it



H.J. Moseley

has atomic number less by one unit compared to iodine. This atomic number concept forced the periodic law to be changed.

The periodic law is changed from atomic weight concept to atomic number concept and now it is called the *modern periodic law*.

We know that Mendeleeff's periodic law is stated as "The properties of elements are the periodic functions of their atomic weights". Now, let us try to understand modern periodic law.

The modern periodic law may be stated as "the properties of the elements are periodic functions of their atomic numbers."

Based on the modern periodic law, the modern periodic table which is given here (page 132) is proposed. It is the extension of the original Mendeleeff's periodic table known as short form of the table and this modern table is called the long form of the periodic table. It is given in fig (2). Atomic number of an element ( $Z$ ) indicates not only the positive charges i.e., the protons in the nucleus of the atom of the element but also the number of electrons in the neutral atom of that element.

The physical and chemical properties of atoms of the elements depend not on the number of protons but on the number of electrons and their arrangements (electronic configurations) in atoms. Therefore, the modern periodic law may be stated as "The physical and chemical properties of elements are the periodic functions of the electronic configurations of their atoms."

### Positions of elements in the Modern Periodic Table

The modern periodic table has eighteen vertical columns known as *groups* and seven horizontal rows known as *periods*.

Let us see what decides the position of an element in modern periodic table.

We can explain the classification of the elements in the modern periodic table in terms of certain electron arrangements which are periodically repeated. The elements with similar outer shell (valence shell) electronic configurations in their atoms are in the same column called **group**. Elements listed in a group down to it are in the order of their increasing principal quantum numbers.

In the chapter 'Structure of atom' you have learnt that 's' sub-shell with one orbital contains a maximum of two electrons. Each 'p' sub-shell contains 3 orbitals and accommodates a maximum of six electrons. The 'd' sub-shell contains 5 orbitals and accommodates a maximum of 10 electrons and 'f' sub-shell contains 7 orbitals with 14 electrons maximum. Depending upon to which sub-shell the differentiating electron, i.e., the last coming electron enters in the atom of the given element, the elements are classified as 's', 'p', 'd' and 'f' block elements.

For example, sodium (Na) gets its new coming electron (differentiating

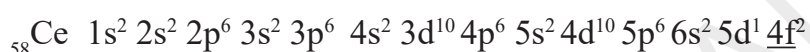
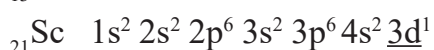
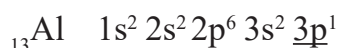
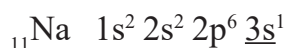


# The Modern Periodic Table of the Elements

		1 <i>IA</i>		2 <i>IIA</i>		3 <i>IIIB</i> 4 <i>IVB</i> 5 <i>VB</i> 6 <i>VIB</i> 7 <i>VIB</i> 8 <i>VIB</i> 9 <i>VIB</i> 10 <i>VIB</i> 11 <i>IB</i> 12 <i>IIB</i>										13 <i>IIIA</i>		14 <i>IVA</i>		15 <i>VA</i>		16 <i>VIA</i>		17 <i>VIIA</i>		18 <i>VIIIA</i>																																																																																																																																																																																																																	
		Symbol		Atomic Number		Atomic Weight		Name																																																																																																																																																																																																																																			
1	<b>H</b> 1 Hydrogen	2	<b>He</b> 2 Helium	3	<b>Li</b> 3 Lithium	4	<b>Be</b> 4 Beryllium	5	<b>B</b> 5 Boron	6	<b>C</b> 6 Carbon	7	<b>N</b> 7 Nitrogen	8	<b>O</b> 8 Oxygen	9	<b>F</b> 9 Fluorine	10	<b>Ne</b> 10 Neon	11	<b>Na</b> 11 Sodium	12	<b>Mg</b> 12 Magnesium	13	<b>Al</b> 13 Aluminium	14	<b>Si</b> 14 Silicon	15	<b>P</b> 15 Phosphorus	16	<b>S</b> 16 Sulphur	17	<b>Cl</b> 17 Chlorine	18	<b>Ar</b> 18 Argon	19	<b>K</b> 19 Potassium	20	<b>Ca</b> 20 Calcium	21	<b>Sc</b> 21 Scandium	22	<b>Ti</b> 22 Titanium	23	<b>V</b> 23 Vanadium	24	<b>Cr</b> 24 Chromium	25	<b>Mn</b> 25 Manganese	26	<b>Fe</b> 26 Iron	27	<b>Co</b> 27 Cobalt	28	<b>Ni</b> 28 Nickel	29	<b>Cu</b> 29 Copper	30	<b>Zn</b> 30 Zinc	31	<b>Ga</b> 31 Gallium	32	<b>Ge</b> 32 Germanium	33	<b>As</b> 33 Arsenic	34	<b>Se</b> 34 Selenium	35	<b>Br</b> 35 Bromine	36	<b>Kr</b> 36 Krypton	37	<b>Rb</b> 37 Rubidium	38	<b>Sr</b> 38 Strontium	39	<b>Y</b> 39 Yttrium	40	<b>Zr</b> 40 Zirconium	41	<b>Nb</b> 41 Niobium	42	<b>Mo</b> 42 Molybdenum	43	<b>Tc</b> 43 Technetium	44	<b>Ru</b> 44 Ruthenium	45	<b>Rh</b> 45 Rhodium	46	<b>Pd</b> 46 Palladium	47	<b>Ag</b> 47 Silver	48	<b>Cd</b> 48 Cadmium	49	<b>In</b> 49 Indium	50	<b>Sn</b> 50 Tin	51	<b>Sb</b> 51 Antimony	52	<b>Te</b> 52 Tellurium	53	<b>I</b> 53 Iodine	54	<b>Xe</b> 54 Xenon	55	<b>Cs</b> 55 Cesium	56	<b>Ba</b> 56 Barium	57	<b>La</b> 57 Lanthanum	58	<b>Ce</b> 58 Cerium	59	<b>Pr</b> 59 Praseodymium	60	<b>Nd</b> 60 Neodymium	61	<b>Pm</b> 61 Promethium	62	<b>Sm</b> 62 Samarium	63	<b>Eu</b> 63 Europium	64	<b>Gd</b> 64 Gadolinium	65	<b>Tb</b> 65 Terbium	66	<b>Dy</b> 66 Dysprosium	67	<b>Ho</b> 67 Holmium	68	<b>Er</b> 68 Erbium	69	<b>Tm</b> 69 Thulium	70	<b>Yb</b> 70 Ytterbium	71	<b>Lu</b> 71 Lutetium	72	<b>Ra</b> 88 Radium	73	<b>Fr</b> 87 Francium	74	<b>Ac</b> 89 Actinium	75	<b>Rf</b> 104 Rutherfordium	76	<b>Hf</b> 72 Hafnium	77	<b>Ta</b> 73 Tantalum	78	<b>W</b> 74 Tungsten	79	<b>Re</b> 75 Rhenium	80	<b>Os</b> 76 Osmium	81	<b>Ir</b> 77 Iridium	82	<b>Pt</b> 78 Platinum	83	<b>Au</b> 79 Gold	84	<b>Hg</b> 80 Mercury	85	<b>Tl</b> 81 Thallium	86	<b>Pb</b> 82 Lead	87	<b>Bi</b> 83 Bismuth	88	<b>Po</b> 84 Polonium	89	<b>At</b> 85 Astatine	90	<b>Rn</b> 86 Radon	91	<b>Th</b> 90 Thorium	92	<b>Pa</b> 91 Protactinium	93	<b>U</b> 92 Uranium	94	<b>Np</b> 93 Neptunium	95	<b>Pu</b> 94 Plutonium	96	<b>Am</b> 95 Americium	97	<b>Cm</b> 96 Curium	98	<b>Bk</b> 97 Berkelium	99	<b>Cf</b> 98 Californium	100	<b>Es</b> 99 Einsteinium	101	<b>Fm</b> 100 Fermium	102	<b>Md</b> 101 Mendelevium	103	<b>No</b> 102 Nobelium	104	<b>Lr</b> 103 Lawrencium	105	<b>Un</b> 104 Ununquadium	106	<b>Uu</b> 105 Ununpentium	107	<b>Uub</b> 106 Ununhexium	108	<b>Uuq</b> 107 Ununseptium	109	<b>Uuq</b> 108 Ununseptium	110	<b>Uuq</b> 109 Ununseptium	111	<b>Uuq</b> 110 Ununseptium	112	<b>Cn</b> 112 Copernicium	113	<b>Nh</b> 113 Nihonium	114	<b>Fl</b> 114 Flerovium	115	<b>Mc</b> 115 Moscovium	116	<b>Lv</b> 116 Livermorium	117	<b>Ts</b> 117 Tennessine	118	<b>Og</b> 118 Oganesson

electron) into 3s level. Therefore 'Na' is an s-block element. Aluminium (Al) gets its differentiating electron into 'p' subshell and it is a p-block element. Scandium (Sc) gets its differentiating electron into 'd' subshell. Therefore it is a d-block element. Cerium (Ce) gets its new coming electron into 'f' subshell, hence, it is an f-block element.

Let us observe the electronic configurations of the following elements. The last coming electron is underlined.



Z	Elements	n	1	2	3	4	5	6									
		<i>l</i>	0	0	1	0	1	2	0	1	2	3	0	1	2	3	0
		Sub Shell	1s	2s	2p	3s	3p	3d	4s	4p	4d	4f	5s	5p	5d	5f	6s
11	Na		2	2	6	<u>1</u>											
13	Al		2	2	6	2	<u>1</u>										
21	Sc		2	2	6	2	6	<u>1</u>	2								
58	Ce		2	2	6	2	6	10	2	6	10	<u>1</u>	2	6	1		2

Table-4

## Groups

The vertical columns in the periodic table are known as groups. There are eighteen groups in long form of periodic table. They are represented by using Roman numeral I through VIII with letters A and B in traditional notation.

According to latest recommendation of the IUPAC, these groups are represented by Arabic numerals 1 through 18 with no A and B designations. We use the latest system with the traditional heading following in parenthesis.

Eg: Group 2 (II A); Group 16 (VIA)

Group of elements is also called *element family* or *chemical family*.

For example Group 1 (IA) has from Li to Fr with outer shell electronic configuration  $ns^1$  and is called *Alkali metal* family.

### Activity 2

Some main group elements of s-block and p-block have family names as given in the following table.

Observe the long form of the periodic table and complete the table with proper information.

**Table-5**

Group No.	Name of the element family	Elements		Valence shell configuration	Valence electrons	Valency
		From	To			
1 (IA)	Alkali metal family	Li	Fr	$ns^1$	1	1
2 (IIA)	Alkali earth metal family					
13 (IIIA)	Boron family					
14 (IVA)	Carbon family					
15 (VA)	Nitrogen family					
16 (VIA)	Oxygen family or (Chalcogen family)					
17 (VIIA)	Halogen family					
18 (VIIIA)	Noble gas family					

### Periods

The horizontal rows in the periodic table are called periods. There are seven periods in the modern periodic table. These periods are represented by Arabic numerals 1 to 7.

1. The number of main shells present in the atom of particular element decides to which period it belongs. For example, hydrogen (H) and helium (He) atoms contain only one main shell (K). Therefore they belong to period-1. Similarly, the elements Li, Be, B, C, N, O, F and Ne contain two main shells (K and L) in their atoms. Therefore they belong to period-2.

### **(?) Do you know?**

- Do you know how the names of certain families of elements are derived?  
**Alkali metal family:** aliquid = plant ash, Na, K etc.... were obtained from plant ash, group IA elements are called alkali metals family.  
**Chalcogen family:** chalcogenous = ore product, as the elements in group 16(VIA) form ores with metals. They are called chalcogenous family.  
**Halogen family:** halos = sea salt, genus = produced. As most of the elements in group 17(VIIA) are obtained from nature as sea salt. They are called as halogen family.  
**Noble gases:** as the elements of group 18(VIIIA) are chemically least active. They are called as noble gases. Their outer shell electronic configurations are basis for octet rule.

2. The number of elements in period depend on how electrons are filled into various shells. Each period starts with a new main shell 's' subshell

and ends when the main shell is filled with respect to the 's' and 'p' subshells (except the first period).

The first period starts with K-shell. The first main shell (K) contains only one sub-shell, the (1s). For this subshell only two types of electronic configurations are possible and they are  $1s^1$  (H) and  $1s^2$  (He). Therefore, the first period contains only two elements.

3. Second period starts with the 2<sup>nd</sup> main shell (L). L-shell has two sub-shells, namely, 2s and 2p. Eight types of configurations are possible in this shell (L) like  $2s^1$  and  $2s^2$  and  $2p^1$  to  $2p^6$ . Hence the second period contains 8 elements Li, Be, B, C, N, O, F and Ne in the order given. Thus, the 2<sup>nd</sup> period consists two s-block elements (Li, Be) and six p-block elements (B to Ne).
4. Third period starts with third main shell (M). This shell (M) has 3 sub-shells, namely, 3s, 3p and 3d, but while electrons are being filled into the shell '3d' gets electrons only after '4s' is filled. Therefore, the 3<sup>rd</sup> period contains again 8 elements, which includes two s-block elements (Na, Mg) and six p-block elements (Al to Ar).
5. Fourth main shell (N). This shell (N) has four sub-shells namely 4s, 4p, 4d and 4f, but while electrons are being filled into the shell, electrons enter the atoms in the order 4s, 3d and 4p. Due to this, the fourth period contains 18 elements which includes two s-block (K, Ca), 10 elements from d block (Sc to Zn) and six elements from p-block ( $_{31}\text{Ga}$  to  $_{36}\text{Kr}$ ). There are altogether eighteen elements in the fourth period.

On the same lines, we can explain why there are 18 elements in the fifth period ( $_{37}\text{Rb}$  to  $_{54}\text{Xe}$ ).

There are thirty two elements in the Sixth period from  $_{55}\text{Cs}$  to  $_{86}\text{Rn}$  which includes 2 elements from s-block (6s) 14 elements from f-block (4f) 10 elements from d-block (5d) and 6 elements from p-block (6p).

'4f' elements are called *Lanthanoids* or *lanthanides*. Elements from

### **(?) Do you know?**

'*Ide*' means 'heir' and it is used generally for a change like *Cl* to *Ct*. '*Cl*' is chlorine atom and *Cl* is chloride ion. '*Oid*' means 'the same'.

Some scientists suggest lanthanoids as  $_{57}\text{La}$  to  $_{70}\text{Yb}$ , some suggest them as  $_{58}\text{Ce}$  to  $_{71}\text{Lu}$  and some take  $_{57}\text{La}$  to  $_{71}\text{Lu}$  (15 elements). There is another argument that even  $_{21}\text{Sc}$  and  $_{39}\text{Y}$  should be included in lanthanoids. All these suggestions have substance because  $_{21}\text{Sc}$ ,  $_{39}\text{Y}$  and  $_{57}\text{La}$  to  $_{71}\text{Lu}$  all have the similar outer shells configurations.

Also in the case of actinoids. There are different arguments like actinoids are from  $_{90}\text{Th}$  to  $_{103}\text{Lr}$  or  $_{89}\text{Ac}$  to  $_{102}\text{No}$  or  $_{89}\text{Ac}$  to  $_{103}\text{Lr}$ .

$_{58}\text{Ce}$  to  $_{71}\text{Lu}$  possess almost the same properties as  $_{57}\text{La}$ . So, the name lanthanoids is the most appropriate one for these elements.

7<sup>th</sup> period is incomplete and contains 2 elements from s-block (7s) 14 elements from f-block (5f), 10 elements from d-block (6d) and some elements from p-block (7p). The 5f elements are called *Actinoids* or as *Actinides*. They are from  $_{90}\text{Th}$  to  $_{103}\text{Lr}$ .

The f-block elements known as lanthanoids and actinoids are shown separately at the bottom of the periodic table.



### Think and discuss

- Why lanthanoids and actinoids placed separately at the bottom of the periodic table?
- If they are inserted within the table imagine how the table would be?

## Metals and Non metals

You have learnt about the properties of metals in the chapter Metals and Non Metals in class VIII. Let us study the metallic properties of elements in periodic table.

The elements with three or less electrons in the outer shell are considered to be metals and those with five or more electrons in the outer shell are considered to be non metals. We may find some exceptions to this. 'd' block elements (3<sup>rd</sup> group to 12<sup>th</sup> group) are metals and they are also known as transition metals and the metallic character of d-block elements decreases gradually from left to right in periodic table. Lanthanoids and actinoids actually belong to 3<sup>rd</sup> group (III B) which is within the transition elements: hence they are called the inner transition elements.

Metalloids or semi-metals are elements which have properties that are intermediate between the properties of metals and non metals. They possess properties like metals but are brittle like non metals. They are generally semi conductors. Eg: B, Si, As, Ge.

All elements in s-block are metals, whereas in p-block (except 18<sup>th</sup> group) there are metals, non metals and metalloids. In periodic table you will notice a staircase like demarcation. The elements to the left of this demarcation are metals and to the right are non-metals. The elements on staircase (or) very near to it like B, Si, As, Ge etc., are metalloids.

## Periodic properties of the elements in the modern table

The modern periodic table is organized on the basis of the electronic configuration of the atoms of elements. Physical and chemical properties of elements are related to their electronic configurations particularly the outer shell configurations. The atoms of the elements in a group possess

similar electronic configurations. Therefore, we expect all the elements in a group should have similar chemical properties and there should be a regular gradation in their physical properties from top to bottom.

Similarly, across the table, i.e., from left to right in any period elements get an increase in the atomic number by one unit between any two successive elements. Therefore, the electronic configuration of valence shell of any two elements in a given period is not same. Due to this reason elements along a period possess different chemical properties with regular gradation in their physical properties from left to right. To understand this we will take some properties of elements and discuss how they vary in groups and in periods.

### Properties of elements and their trends in Groups and in Periods

**1. Valence:** Valence (or) valency of an element was defined as the combining power of an element with respect to hydrogen, oxygen or indirectly any other element through hydrogen and oxygen.

Valence of an element with respect to hydrogen is the number of hydrogen atoms with which one atom of that element chemically combines. Valence of an element with respect to oxygen is twice the number of oxygen atoms with which one atom of that element combines. Note that the group number of an element gives the maximum valence of that element as per old notation that is I to VIII groups but it is 18-group number as per IUPAC numbering.

For example one atom of 'Na' chemically combines with one atom of 'H' to give NaH. Therefore, the valence of Na is 1. One atom of 'Ca' combines with one atom of 'O' to give CaO. So the valency of Ca is 2.

In general, the valence of an element with respect to hydrogen is its traditional group number. If the element is in the group V or above, its valence is  $8 - \text{group number}$ . For example, chlorine valence is  $8 - 7 = 1$ .

In general, each period starts with valency 1 for 1<sup>st</sup> group elements, increases upto 4 with respect to the group number and then decreases from 4 to 3 to 2 to 1 to zero in the following groups (this is applicable only for main group elements i.e., 's' and 'p' block elements with respect to hydrogen).

Now a days the valence of an element is generally taken as the number of valence shell (outer most shell) electrons in its atom. Oxidation number concept almost is the latest substitute to the valence concept in the modern literature.

#### Activity 3

- Find out the valencies of first 20 elements.
- How does the valency vary in a period on going from left to right?
- How does the valency vary on going down a group?

#### Atomic radius

Atomic radius of an element may be defined as the distance from the centre of the nucleus of the atom to its outermost shell.

Atomic radius of an element is not possible to measure in its isolated state. This is because it is not possible to determine the location of the electron that surrounds the nucleus. However, we can measure the distance between the nuclei of adjacent atoms in a solid. From this we can estimate the size of the atom by assigning half of this distance to the radius of each atom. This method is best suited to elements such as the metals that exist in the solid state. More than 75 percent of the elements are metals and atomic radii of metals are called *metallic radii*. Another way of estimating the size of an atom is to measure the distance between the two atoms in covalent molecules. The size of a chlorine atom is estimated by measuring the length of the covalent bond between two chlorine atoms in a  $Cl_2$  molecule. Half of this distance is taken as *atomic radius* which is called as the *covalent radius* of chlorine atom.

Atomic radius is measured in 'pm' (pico meter) units.

$$1 \text{ pm} = 10^{-12} \text{ m}$$

### Variation of atomic radii in group

Atomic radii increase from top to bottom in a group (column) of the periodic table. As we go down in a group, the atomic number of the element increases. Therefore to accommodate more number of electrons, more shells are required. As a result the number of shells in a group from top to bottom increases. The distance between the nucleus and the outer shell of the atom increases. Hence the atomic size increases with atomic number when we go down the group.

**Table-6**

Group	Element (atomic radius in pm)
<b>Group 1:</b>	Li (152), Na (186), K (231), Rb (244) and Cs (262)
<b>Group 17:</b>	F (64), Cl (99), Br (114), I (133) and At (140)

### Variation of atomic radii in period

Atomic radii of elements decrease across a period from left to right. As we go to right, electrons enter into the same main shell or even inner shell in case of 'd' block and 'f' block elements. Therefore, there should be no change in distance between nucleus and outer shell but nuclear charge increases because of the increase in the atomic number of elements in period. Hence, the nuclear attraction on the outer shell electrons increases. As a result the size of the atom decreases.

**Table-7**

Period	Element (atomic radius in pm)
2 <sup>nd</sup> period	Li (152), Be (111), B (88), C (77), N (74), O (66), F (64)
3 <sup>rd</sup> period	Na (186), Mg (160), Al (143), Si (117), P(110), S(104), Cl(99)

- Do the atom of an element and its ion have same size?

Let us consider the following situation.

Assume that sodium (Na) atom has lost an electron and formed a cation of sodium (Na<sup>+</sup>).

Which one between Na and Na<sup>+</sup> would have more size? Why?

Atomic number of sodium (Na) is 11. Therefore sodium (Na) atom contains 11 protons and 11 electrons with outer electron as 3s<sup>1</sup>. On the other hand Na<sup>+</sup> ion has 11 protons but only 10 electrons. The 3s shell of Na<sup>+</sup> level has no electron in it. Hence its outer shell configuration is 2s<sup>2</sup> 2p<sup>6</sup>. As proton number is more than electrons in it, the nucleus of Na<sup>+</sup> ion attracts outer shell electrons with strong nuclear force. As a result the Na<sup>+</sup> ion shrinks in size. Therefore, the size of Na<sup>+</sup> ion is less than 'Na' atom. In general the positive ion (cation) of an element has less size than its neutral atom Eg. Na (157pm) Na<sup>+</sup> (98pm); K (203pm) K<sup>+</sup> (133pm); Mg (136pm) Mg<sup>2+</sup> (65pm); Al (125pm) Al<sup>3+</sup> (50pm) for neutral atoms covalent radii are give.

**Consider another example:** Assume that chlorine (Cl) atom has gained an electron to form anion of chlorine (Cl<sup>-</sup>) i.e. chloride ion.

- Which one, between Cl and Cl<sup>-</sup> would have more size? Why?

Electronic configuration of chlorine (Cl) atom is 1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>6</sup> 3s<sup>2</sup> 3p<sup>5</sup> and the electronic configuration of chloride (Cl<sup>-</sup>) ion is 1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>6</sup> 3s<sup>2</sup> 3p<sup>6</sup>. Both chlorine and chloride ion have 17 protons each but there are 17 electrons in chlorine atom, where as 18 electrons in chloride ion. Therefore, the nuclear attraction is less in Cl<sup>-</sup> ion when compared with chlorine atom. Therefore the size of the chlorine (Cl) atom is less size than Cl<sup>-</sup> ion. In general negative ion (anion) of an element has bigger size than its neutral atom.

Chloride ion of Cl (99pm) Cl<sup>-</sup> (181pm); F (64pm) F<sup>-</sup> (133pm); O (73pm) O<sup>2-</sup> (140pm); N (75pm) N<sup>3-</sup> (171pm);

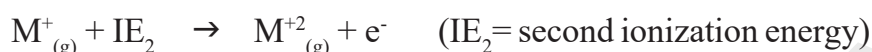
- Which one in each of the following pairs is larger in size?

(a) Na, Al (b) Na, Mg<sup>2+</sup> (c) S<sup>2-</sup>, Cl<sup>-</sup> (d) Fe<sup>2+</sup>, Fe<sup>3+</sup> (e) C<sup>4-</sup>, F<sup>-</sup>



## Ionization Energy

The energy required to remove an electron from the outer most orbit or shell of a neutral gaseous atom is called ionization energy. The energy required to remove the first electron from the outer most orbit or shell of a neutral gaseous atom of the element is called its first ionization energy. The energy required to remove an electron from uni- positive ion of the element is called the 2<sup>nd</sup> ionization energy of that element and so on.



### Think and discuss

- Second ionization energy of an element is higher than its first ionization energy. why?

Ionization energy of an element depends on its

**1. Nuclear charge:** more the nuclear charge more is the ionization energy.

**eg:** Between  $_{11}\text{Na}$  and  $_{17}\text{Cl}$ , Chlorine atom has more ionization energy.

**2. Screening effect or sheilding effect:** more the shells with electrons between the nucleus and the valence shell, they act as screens and decrease nuclear attraction over valence electrons. This is called the *screening effect*. More the screening effect, less is the ionization energy. Between  $_3\text{Li}$  and  $_{55}\text{Cs}$ , the element  $_{55}\text{Cs}$  with more inner shells has less ionization energy.

**3. Penetration power of the orbitals:** orbitals belonging to the same main shell have different piercing power towards the nucleus, for examle  $4s > 4p > 4d > 4f$  in the penetration. There fore, it is easier to remove 4f electron than 4s. Between  $_4\text{Be } 1s^2 2s^2$  and  $_5\text{B } 1s^2 2s^2 2p^1$ , the element B has less ionization energy due to less penetration power of '2p' compared to '2s'

**4. Stable configuration:** it is easier to remove one electron from  $_8\text{O}$  ( $1s^2 2s^2 2p^4$ ) than  $_7\text{N}$  ( $1s^2 2s^2 2p^3$ ). This is because,  $_7\text{N}$  has stable half filled configuration.

**5. Atomic radius:** more the atomic radius, less is the ionization energy.

Therefore, ionization energy of 'F' is greater than that of 'I' and the ionization energy of 'Na' is more than that of 'Cs'.

Ionization energy decreases as we go down in a group and generally increases from left to right in a period.

Ionization energy is expressed in  $\text{kJ mol}^{-1}$

Ionization energy is also called the ionization potential but when we use the term the ionization potential, it is better to write the unit  $\text{eV atom}^{-1}$ .

**Ionisation Energy Values are given in the following table in KJ/mol.**

<b>H</b> 1312.1							<b>He</b> 2372.3
<b>Li</b> 520.2	<b>Be</b> 899.5	<b>B</b> 800.6	<b>C</b> 1086.5	<b>N</b> 1402.3	<b>O</b> 1313.9	<b>F</b> 1681	<b>Ne</b> 2080.7
<b>Na</b> 495.9	<b>Mg</b> 737.7	<b>Al</b> 577.5	<b>Si</b> 786.5	<b>P</b> 1011.8	<b>S</b> 999.6	<b>Cl</b> 1251.5	<b>Ar</b> 1520.6
<b>K</b> 418.8	<b>Ca</b> 589.8	<b>Ga</b> 578.8	<b>Ge</b> 762	<b>As</b> 947	<b>Se</b> 940.9	<b>Br</b> 1139.9	<b>Kr</b> 1350.8
<b>Rb</b> 403.0	<b>Sr</b> 549.5	<b>In</b> 558.2	<b>Sn</b> 708.4	<b>Sb</b> 834	<b>Te</b> 869.3	<b>I</b> 1008.4	<b>Xe</b> 1170.4

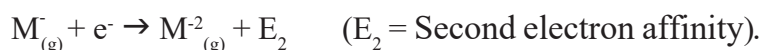
### IONIZATION POTENTIAL VALUES

Element	1st	2nd	3rd	4th	5th	6th
<b>H</b>	1312.1					
<b>He</b>	2372.3	5220				
<b>Li</b>	520.2	7300	11750			
<b>Be</b>	899.5	1760	14850	20900		
<b>B</b>	800.6	2420	3660	25020	32600	
<b>C</b>	1086.5	2390	4620	6220	37820	46990
<b>Al</b>	577.5	1810	2750	11580	14820	18360
<b>Ga</b>	578.8	1980	2970	6170	8680	71390

### Electron affinity - Electron gain enthalpy

Atoms of some elements gain electrons while forming ionic compounds. An atom is able to gain an electron only when the electron outside the atom is attracted by its nucleus. Attraction involves the liberation of energy.

The electron affinity of an element is defined as the energy liberated when an electron is added to its neutral gaseous atom. Electron affinity of an element is also called electron gain enthalpy of that element.



The energy liberated when an electron is added to a uni-negative ion of the element is called the 2<sup>nd</sup> electron affinity of that element. However, practically no element shows liberation of energy when the 2<sup>nd</sup> electron is added to its uni-negative ion. It does not mean that di-negative or tri-negative ions do not form. They do form, but for adding 2<sup>nd</sup> electron, energy in another way like bond formation must be given.

**Table-8**

Groups	Electron affinity value (in kJ mol <sup>-1</sup> )
VIIA (halogens)	F(-328); Cl(-349); Br (-325); I(-295) At(-270)
VIA (chalcogens)	O(-141); S(-200); Ge(-195) Te(-190) PO (-174)

Electron gain enthalpy values decrease as we go down in a group, but increase along a period from left to right. Metals have very low electron gain enthalpy values and alkaline earth metals have even positive values. Note that the negative sign for energy value in table indicates that energy is liberated or lost, and the positive sign tells that the energy is gained or absorbed. All the factors which influence the ionization energy would also influence the electron gain enthalpy.



### Think and discuss

- The calculated electron gain enthalpy values for alkaline earth metals and noble gases are positive. How can you explain this?
- The second period element for example 'F' has less electron gain enthalpy than the third period element of the same group for example 'Cl'. Why?

### Electronegativity

The ionization energy and the electron gain enthalpy are properties of isolated atoms of elements. There has been a need to have a comparative

scale relating to the abilities of elements to attract electrons when their atoms are combined. For this purpose, the concept of electronegativity is introduced.

The *electronegativity* of an element is defined as the relative tendency of its atom to attract electrons towards it self when it is bonded to the atom of another element.

All the factors that influence the ionization energy and the electron affinity of elements influence the electronegativity values of those elements. Because of this, Mulliken proposed that the electronegativity of an element is the average value of its ionization energy and electron affinity.

$$\text{Electronegativity} = \frac{\text{ionization energy} + \text{electron affinity}}{2}$$

Pauling assigned the electronegativity values for elements on the basis of their bond energies. He assumed that the electronegativity of hydrogen is 2.20 and calculated the values of other elements with respect to hydrogen. Observe the values in the following example

**Table-9**

Period/group	Element (electronegativity with respect to hydrogen)
Halogens:	F(4.0), Cl(3.0), Br(2.8), I(2.5)
2 <sup>nd</sup> period:	Li(1.0), Be(1.47), B(2.0), C(2.5), N(3.0), O(3.5), F(4.0), Ne(-)

Electronegativity values of elements decrease as we go down in a group and increase along a period from left to right. The most electronegative element is 'F' and the least electronegative stable element is 'Cs'.

### **Metallic and Non-Metallic Properties**

Metals generally show less electronegative character. In compounds, they generally show a tendency to remain as positive ions. This property is often termed as electropositive character. Metals are electropositive elements.

Non metals are generally more electronegative due to their smaller atomic radii.

Let us examine the elements of 3<sup>rd</sup> period.

3<sup>rd</sup> period:      Na    Mg    Al    Si    P    S    Cl

We know that Na and Mg are metals, Al and Si are semi metals (metalloids), P, S and Cl are non metals. So we find metals on left side and

non metals on right side of the periodic table. This means metallic character decreases while non metallic character increases as we move along a period (from left to right).

Let us take group 14 (IVA) elements.

IVA group:      C      Si      Ge      Sn      Pb

Here also we know that carbon is nonmetal. Si and Ge are metalloids. Sn and Pb are metals.

So we find nonmetals particularly at the right hand side top and metals at the left and right hand side bottom of the periodic table. This means metallic character increases while non metallic character decreases in a group as we move from top to bottom.



### Key words

*Triad, Octave, Periodic Law, Periodic table, period, group, Lanthanides, Actinides, Element family, Metalloids, Periodicity, Atomic radius, Ionization energy, Electron affinity, Electronegativity, Electropositivity*



### What we have learnt

- Elements are classified on the basis of similarities in their properties.
- Dobereiner grouped the elements into Triads and Newlands gave the law of Octaves.
- Mendeleeff's Periodic law: The physical and chemical Properties of the elements are the periodic functions of their Atomic Masses.
- Moseley's Periodic law : The physical and chemical properties of the elements are the periodic functions of their Atomic numbers.
- Modern Periodic Law: The Physical and chemical Properties of the elements are the periodic functions of their Electronic Configurations.
- Anomalies in arrangement of elements based on increasing atomic mass could be removed when the elements were arranged in order of increasing atomic number, a fundamental property of the element discovered by Moseley.
- Elements in the Modern Periodic table are arranged in 18 groups and 7 periods.
- Elements are classified into s, p, d, f blocks, depending upon to which sub shell, the differentiating electron enters in the atom of the given element.

- All the d- block elements (except Zn group) are known as transition elements and all the f-block elements (both Lanthanides, Actinides) are known as inner transition elements.
- Periodic properties of elements and their trends in groups and in periods

Periodic property	Trend in	
	groups (From top to bottom)	periods (From left to right)
Valency	Same for all elements	increases from 1 to 4 and decreases to 0
Atomic radius	Increasing	Decreasing
Ionisation energy	Decreasing	Generally Increasing
Electron affinity	Decreasing	Increasing
Electronegativity	Decreasing	Increasing
Electropositivity	Increasing	Decreasing
Metallic nature	Increasing	Decreasing
Non-Metallic nature	Decreasing	Increasing



### Improve your learning



#### Reflections on Concepts

1. What are the limitations of Mendeleeff's periodic table? How could the modern periodic table overcome the limitations of Mendeleeff's table? (AS<sub>1</sub>)
2. Define the modern periodic Law. Discuss the construction of the long form of the periodic table. (AS<sub>1</sub>)
3. Explain how the elements are classified into s, p, d and f- block elements in the periodic table and give the advantages of this kind of classification. (AS<sub>1</sub>)
4. Write down the characteristics of the element having atomic number 17. (AS<sub>1</sub>)

Electronic configuration \_\_\_\_\_

Period number \_\_\_\_\_

Group number \_\_\_\_\_

Element family \_\_\_\_\_

No. of valence electrons \_\_\_\_\_

Valency \_\_\_\_\_

Metal or non-metal \_\_\_\_\_

5. Complete the following table using the periodic table. (AS<sub>1</sub>)

Period number	Filling up orbital's (sub shells)	Maximum number of electrons, filled in all the sub shells	Total no. of elements in the period
1			
2			
3			
4	4s, 3d, 4p	18	18
5			
6			
7	7s, 5f, 6d, 7p	32	incomplete

6. Complete the following table using the periodic table. (AS<sub>1</sub>)

Period number	Total no. of elements	Elements		Total no. of elements in			
		From	To	s-block	p-block	d-block	f-block
1							
2							
3							
4							
5							
6							
7							

### Application of concepts

- Given below is the electronic configuration of elements A, B, C, D. (AS<sub>1</sub>)
 

A. $1s^2 2s^2$	1. Which are the elements coming within the same period
B. $1s^2 2s^2 2p^6 3s^2$	2. Which are the ones coming within the same group?
C. $1s^2 2s^2 2p^6 3s^2 3p^3$	3. Which are the noble gas elements?
D. $1s^2 2s^2 2p^6$	4. To which group and period does the element 'C' belong
- s - block and p - block elements (except 18th group elements) are sometimes called as 'Representative elements' based on their abundant availability in the nature. Is it justified? Why? (AS<sub>1</sub>)
- The electronic configuration of the elements X, Y and Z are given below?
 

a) X = 2	b) Y = 2, 6	c) Z = 2, 8, 2
----------	-------------	----------------

  - Which element belongs to second period?
  - Which element belongs to second group?
  - Which element belongs to 18th group?

4. a. State the number of valence electrons, the group number and the period number of each element given in the following table: (AS<sub>1</sub>)

Element	Valence electrons	Group number	Period number
Sulphur			
Oxygen			
Magnesium			
Hydrogen			
Fluorine			
Aluminium			

- b. State whether the following elements belong to a Group (**G**), Period (**P**) or Neither Group nor Period indicating the letters G or P or N. (AS<sub>1</sub>)

Elements	Group / Period / Neighter group nor period
Li,C,O	
Mg, Ca, Ba	
Br, Cl, F	
C,S, Br	
Al, Si, Cl	
Li, Na, k	
C,N,O	
K, Ca, Br.	

5. Identify the element that has the larger atomic radius in each pair of the following and mark it with a symbol (✓). (AS<sub>1</sub>)  
 (i) Mg , Ca (ii) Li , Cs (iii) N , P (iv) B , Al
6. Identify the element that has the lower Ionization energy in each pair of the following and mark it with a symbol (✓). (AS<sub>1</sub>)  
 (i) Mg , Na (ii) Li , O (iii) Br , F (iv) K , Br
7. How does metallic property change when we move  
 i. Down in a group      ii. Across a period?
8. On the basis of atomic numbers predict to which block the elements with atomic number 9,37, 46 and 64 belongs to? (AS<sub>2</sub>)
9. Using the periodic table, predict the formula of compound formed between an element X of group 13 an another element Y of group 16. (AS<sub>2</sub>)
10. An element has atomic number 19. Where would you expect this element be in the periodic table and why? (AS<sub>2</sub>)



### Higher Order Thinking Questions

1. How does the positions of elements in the periodic table help you to predict its chemical properties? Explain with an example. (AS<sub>7</sub>)
2. In period 2, element X is to the right of element Y. Then, find which of the elements have these properties:
  - i) Low nuclear charge
  - (ii) Low atomic size
  - (iii) High ionization energy
  - (iv) High electro negativity
  - (v) More metallic character (AS<sub>1</sub>)

### Multiple choice questions

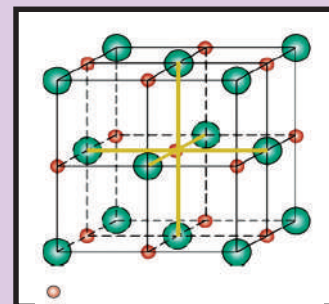
1. Number of elements present in period – 2 of the long form of periodic table [      ]  
a) 2                      b) 8                      c) 18                      d) 32
2. Nitrogen (Z = 7) is the element of group VA of the periodic table. Which of the following is the atomic number of the next element in the same group? [      ]  
a) 9                      b) 14                      c) 15                      d) 17
3. Electron configuration of an atom is 2, 8, 7. To which of the following elements would it be chemically similar? [      ]  
a) nitrogen(Z=7)    b) fluorine(Z=9)    c) phosphorous(Z=15)    d) argon(Z=18)
4. Which of the following is the most active metal? [      ]  
a) lithium              b) sodium              c) potassium              d) rubidium

### Suggested Experiments

1. Aluminium does not react with water at room temperature but reacts with both dil. HCl and NaOH solutions. Verify these statements experimentally. Write your observations with chemical equations. From these observations, can we conclude that Al is a metalloid?

### Suggested Projects

1. Collect the information about reactivity of VIII A group elements (noble gases) from your school library and prepare a report on their special character when compared to other elements of periodic table.
2. Collect information regarding metallic character of elements of IA group and prepare report to support the idea of metallic character increases in a group as we move from top to bottom.



# Chemical Bonding

You have learnt about electron configuration of elements and periodic table in previous lessons. It was learnt that there are over 118 elements.

- How do they usually exist?
- Do they exist as a single atom or as a group of atoms?

In Class IX, we saw that several elements like oxygen, nitrogen and hydrogen exist as diatomic molecules. What is the force that is holding these constituent atoms together in molecules?

- Are there elements which exist as atoms?
- Why do some elements exist as molecules and some as atoms?

In lower classes you have also learnt about the different laws of chemical combinations. Since the formation of chemical compounds takes place as a result of combination of atoms of various elements in different ways, it raises many questions.

- Why do some elements and compounds react vigorously while others are inert?
- Why the chemical formula for water is  $H_2O$  and for sodium chloride  $NaCl$ , why not  $HO_2$  and  $NaCl_2$ ?
- Why do some atoms combine while others do not?

We will try to answer such questions in this chapter.

- Are elements and compounds simply made up of separate atoms individually arranged?
- Is there any attraction between atoms?

Let us take the example of common salt,  $NaCl$ . When you shake salt from a shaker does it separate into sodium and chlorine? No! This shows that the sodium and chlorine atoms are being held together.

- What is that holding them together?

By the late 19<sup>th</sup> century and early twentieth century, scientists knew about three types of forces – gravitational, magnetic and electrostatic. They also knew about the existence of electrons and protons. So it was believed that electrostatic forces were the cause of attraction between atoms in a molecule. When two atoms come sufficiently close together, the electrons of each atom experience the attractive force of the nucleus of the other atom. But the electrons which are negatively charged and repel each other, and the positively charged nuclei also repel each other. The strength of attraction or repulsion will decide bond formation. If attraction is more than the repulsion then atoms combine. If repulsion is more than attraction then the atoms do not combine. The nucleus and the electrons in the inner shell remain unaffected when atoms come close together. But the electrons in the outermost shell (valence shell) of atoms get affected.

### **(?) Do you know?**



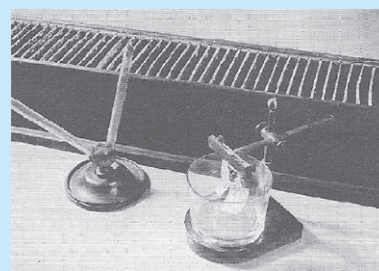
*A Voltaic pile*

It was seen that the metal part of the compound migrated towards the negative electrode and the non-metal part towards the positive electrode. So it was proposed that metals are responsible for positively charged particles and non-metals are responsible for negatively charged particles. The oppositely charged particles are held together by electrostatic forces in a compound. Do you agree with this explanation? Why?

While this explanation could explain bonding in NaCl, KCl etc. it could not explain bonding in carbon compounds or diatomic molecules of elements.

### **Davy's experiment –**

Humphry Davy (1778-1819), a professor of chemistry at the Royal Institution in London, constructed a battery of over 250 metallic plates. In 1807, using electricity from this battery, he was able to extract highly reactive metals like potassium and sodium by electrolysis of fused salts.



*Experimental set up by Davy*

Electrons in valence shell (valence electrons) are responsible for the formation of bonds between atoms.

In previous lessons you studied about exothermic and endothermic reactions. You also studied about reactivity of elements in periodic table.

Some elements are more reactive and some are less reactive;

- Why there is absorption of energy in certain chemical reactions and release of energy in other reactions?
- Where the absorbed energy goes?
- Is there any relation to energy and bond formation between atoms?
- What could be the reason for the change in reactivity of elements?

### Lewis symbols (*or*) Lewis dot structures:

Periodic Classification and arrangement of elements in the periodic table according to the electron configuration gave a new thought about chemical bond.

The discovery of noble gases and the understanding of their electronic configurations helped us in explaining the formation of chemical bonds among the atoms of the elements. Noble gases which belong to zero group (18<sup>th</sup> group or VIII A) are typical gases with almost negligible chemical activity when compared to other elements. They undergo few or no chemical changes. They are more stable and do not form molecules by allowing their atoms to combine among themselves or with the atoms of other elements.

- What could be the reason for this?

Let us investigate.

Consult the periodic table given in the previous chapter and observe the following table:

**Table-1**

Element	Z	Electronic configuration				Valence electrons
		K	L	M	N	
Helium (He)	2	2				2
Neon (Ne)	10	2	8			8
Argon(Ar)	18	2	8	8		8
Krypton(Kr)	36	2	8	18	8	8

Look at the second column and third column. It is clear that all the noble gases have eight electrons in the outermost shell, except Helium (He).

The arrangement of electrons in different shells of atoms (electronic configuration) of 18<sup>th</sup> group elements is shown in the table-1. The valence electrons in the atom of an element is depicted in a short form by *Lewis symbol* or *electron dot structure*. We represent the nucleus and inner shell electrons of the atom by the symbol of the element and electrons in the outer shell by dots or cross marks.

Let us see how? Lewis dot structure of **argon** and **sodium** atoms are written.

Let us start with *argon*. Its atom has eight valence electrons.

First write the symbol of element *argon*. **Ar**

Place the valence electrons around the symbol. Put two dots at a time on each of the four sides of the symbol of the element till all are used up.

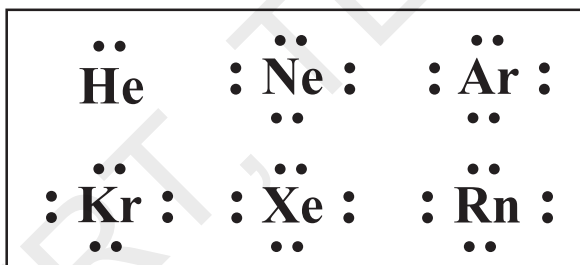
So, we get,



Similarly, for sodium, the number of valence electrons in sodium is one and the symbol is Na. We can also use cross mark for the electrons. The Lewis structure for sodium atom is therefore:



The Lewis dot structures of the atoms of noble gases are shown below:



### Activity 1

Write the Lewis structures of the given elements in the table. Also consult the periodic table and fill in the group number of the element.

**Table – 2:**

Element	Hydrogen	Helium	Beryllium	Boron	Carbon	Nitrogen	oxygen
Group number	1						
Valence electron	1						
Lewis dot structure	H <sup>•</sup>						

Look at the periodic table. Do you see any relation between the number of valence electrons and group numbers? We find that for groups 1-2 and 13 –18, we can use the periodic table to find the number of valence electrons. Group 1 has one outer electron, group 2 has two, and group 13 has three, group 14 has four and so on.

- What did you notice in Lewis dot structure of noble gases and electronic configurations of the atoms of these elements shown in table - 2.

It was found that the elements which participate in chemical reactions get octet or  $ns^2 np^6$  configuration similar to that of noble gas elements. It is to be noted that octet rule is still a rule not the law, because there are considerable exceptions for this rule.

### Electronic theory of valence by Lewis and Kossel

There were number of attempts to explain the chemical bond formation between atoms in terms of electrons but a satisfactory explanation for this concept was given by Kossel and Lewis in 1916. They gave this concept independently. The basis for their theory was valence in terms of electrons. They provided logical explanation of valence on the basis of the lack of chemical activity of noble gases which led to the proposal of *octet rule*.

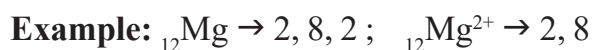
Observe the practical behaviour of atoms of main group elements (Group IA, IIA, IIIA, IVA, VA, VIA, VIIA and zero or VIIIA group elements). When they are allowed to undergo chemical changes, they try to get octet electronic configuration in the outer shells.

Let us understand this with the following illustrations.

Group IA elements (Li to Cs) try to lose one valence shell electron from their atoms to form corresponding uni-positive ions which get octet in their outer shells.



Group IIA elements (Mg to Ba) try to lose two valence electrons from their atoms during chemical changes and form di-positive ions with the octet in the outer shells.



Group IIIA elements try to lose three valence electrons from their atoms and form corresponding tri positive ions with octates in the outer shells.

**Example:**  ${}_{13}\text{Al} \rightarrow 2, 8, 3$  ;  ${}_{13}\text{Al}^{3+} \rightarrow 2, 8$

Group VIA elements try to gain two electrons into the valence shells of their atoms during the chemical changes and form corresponding di negative anions which get octet in their outer shells.

**Example:**  ${}_{8}\text{O} \rightarrow 2, 6$  ;  ${}_{8}\text{O}^{2-} \rightarrow 2, 8$

Group VIIA elements try to gain one electron into the valence shells of their atoms during the chemical changes and form corresponding uni- anions which get octet in their outer shells.

**Example:**  ${}_{9}\text{F} \rightarrow 2, 7$  ;  ${}_{9}\text{F}^{-} \rightarrow 2, 8$

Group VIIIA elements, the noble gases do not try to lose or gain electrons. Generally, helium and neon do not participate in chemical changes. Even other elements of VIIIA do not gain or lose electrons from their atoms when they participate in a very few chemical changes.

**Example:**  ${}_{10}\text{Ne} \rightarrow 2, 8$  ; No electron gain or loss from the neon atom.

Net charge on the ions	Gain Electrons			Magic octet	Lose Electrons		
	-3	-2	-1		+1	+2	+3
	VA	VIA	VIIA	VIIIA	IA	IIA	IIIA
	N	O	F	Ne	Na	Mg	Al
	P	S	Cl	Ar	K	Ca	Ga
	As	Se	Br	Kr	Rb	Sr	In
	Sb	Te	I	Xe	Cs	Ba	Tl
	Bi	Po	At	Rn	Fr	Ra	
	Non metals			Noble gases	Metals		

- What have you observed from the above conclusions about the main groups?
- Why do atoms of elements try to combine and form molecules?

Noble gases of VIIIA possess eight electrons in the valence shells of their atoms. Helium is an exception. Its atom has only two electrons, but its only shell is completely filled. Noble gases with eight electrons in the valence shell in their atoms are highly stable and rarely participate in chemical changes. Therefore it is concluded that any species (atom or ion) with eight electrons in the valence shell is stable.

- Is it accidental that IA to VIIA main group elements during chemical reactions get eight electrons in the outermost shells of their ions, similar to noble gas atoms?

No. It cannot be simply accidental. Eight electrons in the outermost shell definitely gives stability to the ion or atom. Based on the above observations a statement known as “The Octet Rule” is framed.

### **Octet rule:**

It may be stated as “The atoms of elements tend to undergo chemical changes that help to leave their atoms with eight outer-shell electrons.”

Lewis depicted the atom in terms of a positively charged kernel (Kernel is the nucleus and all other electrons in the atom except the outer most shell electrons) and the outershell that could accommodate a maximum of eight electrons.

Chemically active elements do not have an octet of electrons in the valence shell of their atoms. Their reactivity arises from their tendency to achieve the octet, by forming bonds either with atoms of their own type or with atoms of other elements.

The force of attraction between any two atoms or a group of atoms that results a stable entity is called a ‘*chemical bond*’. There are many types of chemical bonds, but here we discuss only about *ionic bond* and *covalent bond*.

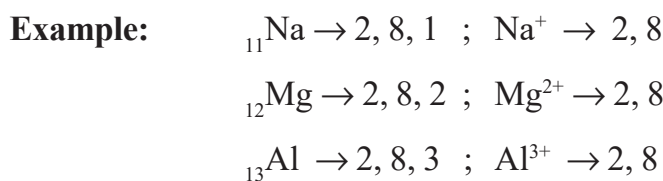
## **Ionic and Covalent bonds**

### **A. Ionic bond**

Kossel proposed the ionic bond (electrostatic bond) based on the following facts.

- i. Ionic bond is formed between atoms of two dissimilar elements due to transfer of electrons from the atom of one element to the other.
- ii. There are highly reactive metals like alkali metals (IA) and highly reactive non-metals like halogens (VIIA) on the left side and right side of the periodic table respectively.
- iii. Noble gases except helium have eight electrons in the valence shells of their atoms. They are chemically inactive and stable.
- iv. To attain eight electrons in the outermost shell similar to noble gases metal atoms that have one two or three electrons in the valence shells generally lose those electrons and form stable positive ions called *cations*.



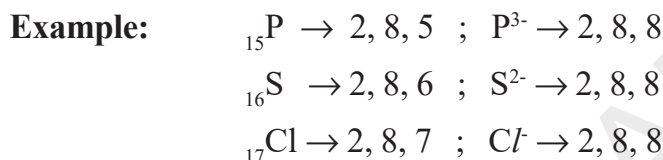


### **(?) Do you know?**

The number of electrons lost from a metal atom is the valence of its element which is equal to its group number.

**Ex.** Na and Mg have valence 1 and 2 respectively.

- v. To attain eight electrons in the outermost shell, non-metal atoms that have 5,6 or 7 valence electrons gain 3,2 or 1 electron respectively and form negative ions known as *anions*.



### **(?) Do you know?**

The number of electrons gained by a non-metal element for its atom is its valency, which is equal to (8 - its group number).

**Ex.** The valency of chlorine is (8 - 7) = 1.

## **Formation of ionic bond**

The positive ions (cations) and negative ions (anions) that are formed due to the transfer of electrons from the metal atoms to the non-metal atoms experience the electrostatic forces and get attracted to form chemical bond. As this bond is between charged particles known as ions, it is called *ionic bond*. Sometimes based on the forces being electrostatic, the bond is also called *the electrostatic bond*. As the valence concept has been explained in terms of electrons, it is also called the *electrovalent bond*.

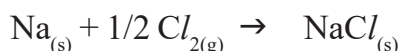
Thus, we can define ionic bond as follows:

The electrostatic attractive force that keeps cation and anion (which are formed from metal atoms and non-metal atoms due to transfer of electrons) together to form a new electrically neutral compounds is called '*ionic bond*'.

- Explain the formation of ionic compounds  $\text{NaCl}$ ,  $\text{MgCl}_2$ ,  $\text{Na}_2\text{O}$  and  $\text{AlCl}_3$ .

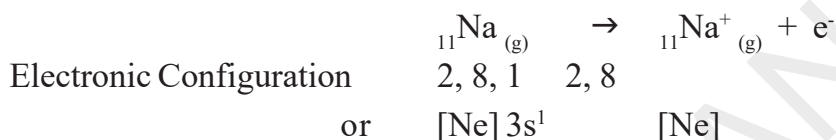
### Eg-1. Formation of sodium chloride (NaCl):

Sodium chloride is formed from the elements sodium and chlorine. It can be explained as follows:



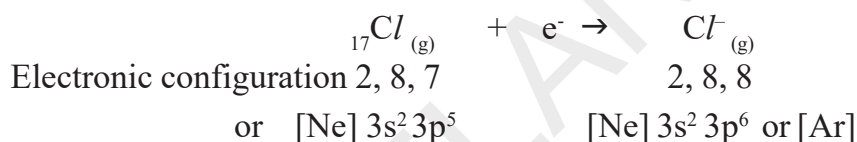
#### Cation formation

When sodium (Na) atom loses one electron to get octet electron configuration it forms a cation (Na<sup>+</sup>) and gets electron configuration that of Neon (Ne) atom.



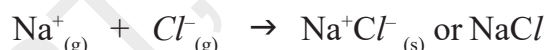
#### Anion formation

Chlorine has shortage of one electron to get octet in its valence shell. So it gains the electron from Na atom to form anion and gets electron configuration as that of argon (Ar).



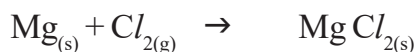
#### Formation of the compound NaCl from its ions:

Transfer of electrons between 'Na' and 'Cl' atoms, results in the formation of 'Na<sup>+</sup>' and 'Cl<sup>-</sup>' ions. These oppositely charged ions get attracted towards each other due to electrostatic forces and form the compound sodium chloride (NaCl).

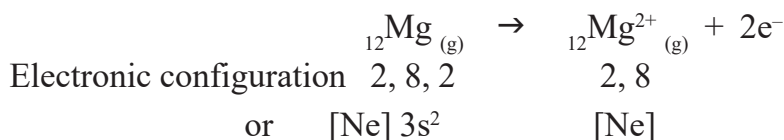


### Eg-2. Formation of magnesium chloride (MgCl<sub>2</sub>):

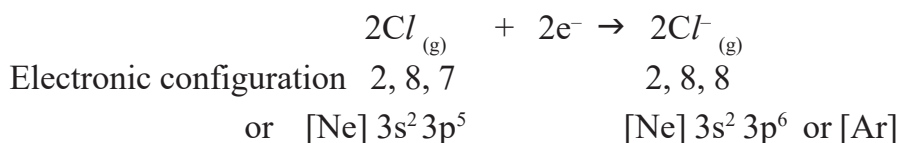
Magnesium chloride is formed from the elements magnesium and chlorine. The bond formation MgCl<sub>2</sub> in brief using chemical equation is as follows:



#### Cation formation



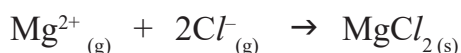
#### Anion formation



The compound  $MgCl_2$  formation from its ions:

$Mg^{2+}$  gets 'Ne' configuration and

Each  $Cl^-$  gets 'Ar' configuration

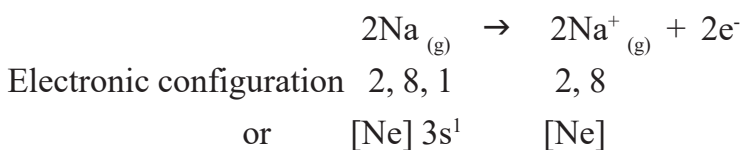


One 'Mg' atom transfers two electrons one each to two 'Cl' atoms and so formed  $Mg^{2+}$  and  $2Cl^-$  attract to form  $MgCl_2$ .

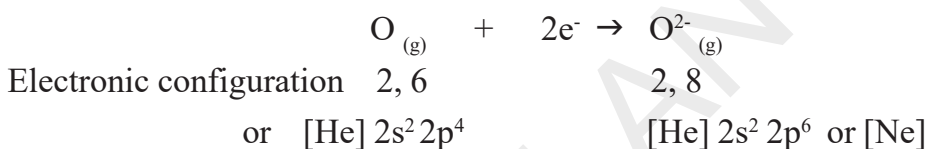
### Eg-3. Formation of di sodium monoxide( $Na_2O$ ):

Di sodium monoxide formation can be explained as follows:

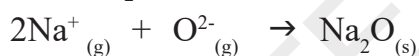
Cation formation ( $Na^+$  formation):



Anion formation ( $O^{2-}$ , the oxide formation):



The compound  $Na_2O$  formation from its ions is as shown.



Two 'Na' atoms transfer one electron each to one oxygen atom to form  $2Na^+$  and  $O^{2-}$

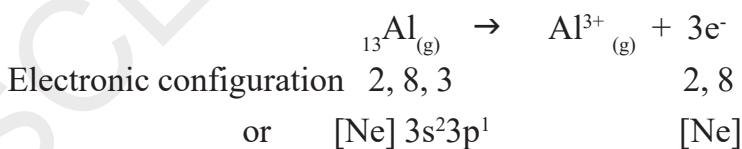
Each  $Na^+$  gets 'Ne' configuration and  $O^{2-}$  gets 'Ne' configuration.

These ions ( $2Na^+$  and  $O^{2-}$ ) attract to form  $Na_2O$ .

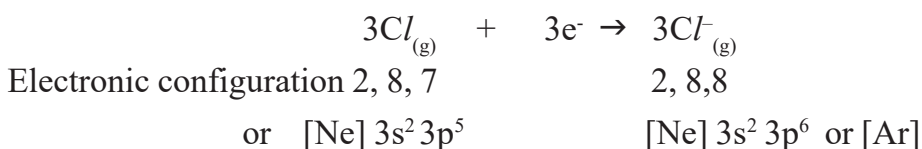
### Eg-4. Formation of aluminium chloride ( $AlCl_3$ ):

Aluminium chloride formation can be explained as follows:

Formation of aluminium ion ( $Al^{3+}$ ), the cation:

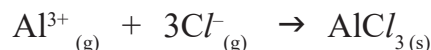


Formation of chloride ion ( $Cl^-$ ), the anion:



Each aluminium atom loses three electrons and three chlorine atoms gain them, one electron each.

The compound  $AlCl_3$  is formed from its component ions by the electrostatic forces of attractions.



### The arrangement of ions in ionic compounds

- How do cations and anions of an ionic compound exist in its solid state?
- Let us explain this with sodium chloride as our example:
- Do you think that pairs of  $Na^+ Cl^-$  as units would be present in the solid crystal?

If you think so, it is not correct. Remember that electrostatic forces are non directional. Therefore, it is not possible for one  $Na^+$  to be attracted by one  $Cl^-$  and vice-versa. Depending upon the size and charge of a particular ion, number of oppositely charged ions get attracted by it, but, in a definite number. In sodium chloride crystal each  $Na^+$  is surrounded by 6  $Cl^-$  and each  $Cl^-$  by six  $Na^+$  ions. Ionic compounds in the crystalline state consist of orderly arranged cations and anions held together by electrostatic forces of attractions in three dimensions. The crystal structure of sodium chloride is given below:

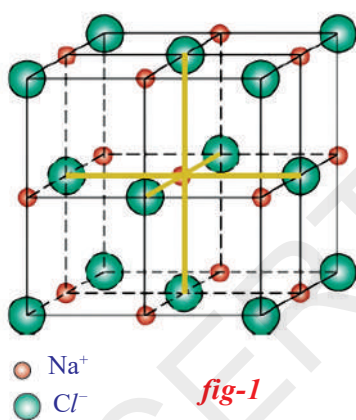


fig-1

$NaCl$  is said to possess face centered cubic lattice crystal structure (see figure-1).

The number of ions of opposite charge that surround a given ion of given charge is known as the coordination number of that given ion.

For example, in sodium chloride crystal, the coordination number of  $Na^+$  is 6 and that of  $Cl^-$  is also 6.

#### Factors affecting the formation of cation and anion:

In previous lesson you have learnt about variation of metallic and non metallic character of elements in a group or period of the periodic table. Recall the facts about metallic and non metallic character of elements.

Generally elements of metals have tendency of losing electron to attain the octet in their valence shell. This property is called as the *metallic character* or *electropositivity*. Elements with more electropositive character form cations. Similarly non metals like oxygen ( ${}_8O$ ), fluorine ( ${}_9F$ ) and chlorine ( ${}_{17}Cl$ ) acquire electron configuration of elements of inert gases by gaining electrons this property is called the *non-metallic character* or *electronegativity of the element*. Elements with more electronegative character form anions.

- Can you explain the reasons for all these?

Ionic bond is formed between atoms of elements with electronegativity difference equal to or greater than 1.9.

In ionic bond formation, you have noticed that atoms either lose electrons or gain electrons to attain octet in valence shell. i.e., in an ionic bond, transfer of electrons takes place between combining atoms.

The tendency of losing electrons to form cations (or) gaining electron to form anions depends on the following factors:

- Atomic size
- Ionisation potential
- Electron affinity
- Electronegativity

The atoms of elements with low ionisation energy, low electron affinity high atomic size and low electronegativity form cations.

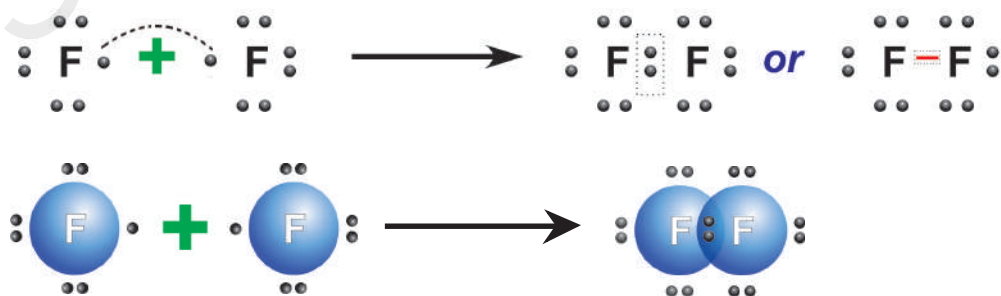
The atoms of elements with high ionisation potential, high electron affinity, small atomic size and high electronegativity form anions.

## B. Covalent bond

G.N. Lewis (1916) proposed that atoms of some elements could achieve an octet in their valence shells without transfer of electrons between them. They can attain octet configuration in their valence shells by sharing the valence electrons with one or more atoms.

The electrons shared between two atoms belong to both the atoms and the sharing of electrons between them leads to the formation of a chemical bond known as *covalent bond*.

For example, take two fluorine atoms which form a stable molecule. Each fluorine atom contributes one electron for bonding and the electron pair that is formed in this way is mutually shared by both the fluorine atoms. Each atom in the  $F_2$  molecule has an octet of valence electrons.



The dots around fluorine atom shows the valence electrons of respective atoms.

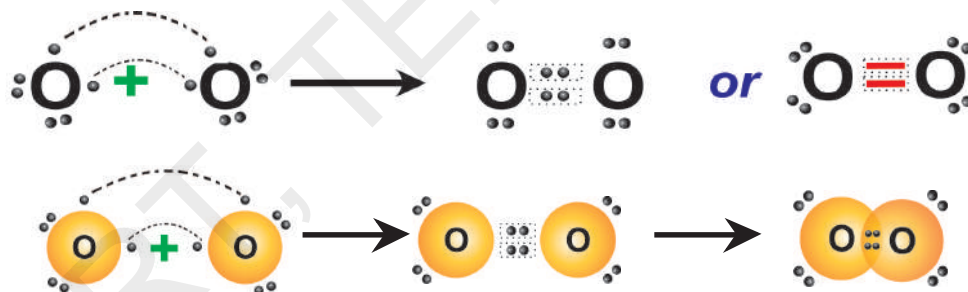
The chemical bond formed between two atoms by mutual sharing of a pair of valence shell electrons so that both of them can attain octet or duplet in their valence shell is called the **covalent bond**.

The prefix co – is used to indicate when things are equal or joined. (for example, co exist, cooperate etc). Here each atom contributes one electron from the valence shell for the bonding. Therefore, the name covalent is given (equal valence electrons contribution) for this bond.

### Formation of O<sub>2</sub> molecule

The electronic configuration of <sub>8</sub>O is 2, 6. Oxygen atom has six electrons in its valence shell. It requires two more electrons to get octet in its valence shell. Therefore oxygen atoms come close and each oxygen atom contributes two electrons for bonding. Thus, there exist two covalent bonds between two oxygen atoms in O<sub>2</sub> molecule as there are two pairs of electrons shared between them.

We can say that a double bond is formed between two oxygen atoms in O<sub>2</sub> molecule. Observe the following figures. Both the oxygen atoms have octet in the valence shell.



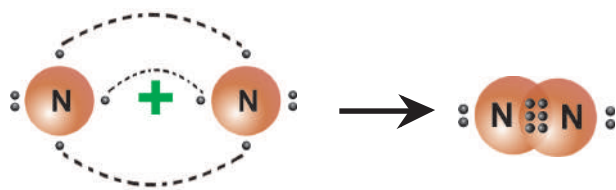
- Can you say what type of bond exists between atoms of nitrogen molecule?

Let us see

### Nitrogen (N<sub>2</sub>) molecule

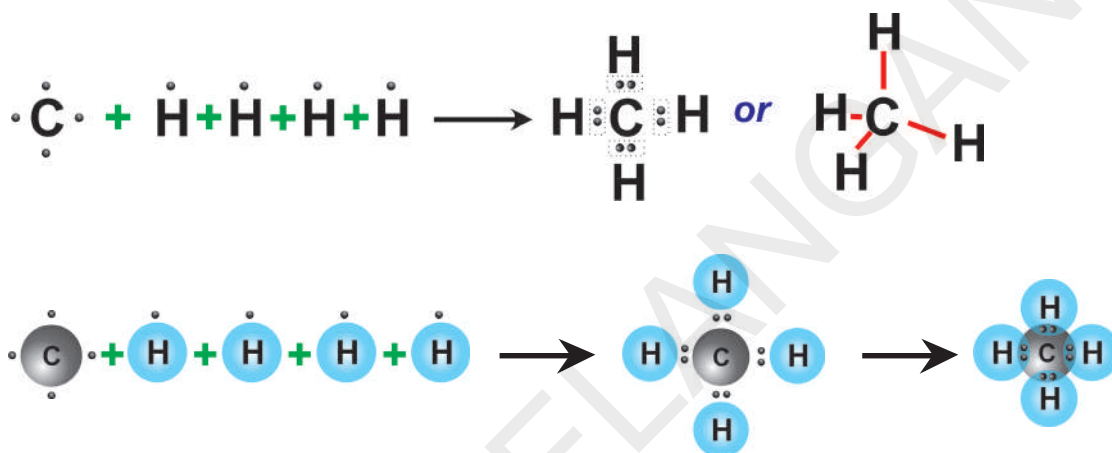
The electronic configuration of 'N' atom is 2,5 and to have octet in the valence shell it requires three more electrons. When two nitrogen atoms approach each other, each atom contributes 3 electrons for bonding. There are six electrons shared between two nitrogen atoms in the form of three pairs. Therefore, there is a triple bond between two nitrogen atoms in N<sub>2</sub> molecule.





### Methane (CH<sub>4</sub>) molecule

In the formation of methane, CH<sub>4</sub> molecule, carbon contributes 4 electrons, (one electron to each hydrogen atom) and 4 hydrogen atoms contribute one electron each. Thus in CH<sub>4</sub> molecule, there are four C – H covalent bonds as shown below:

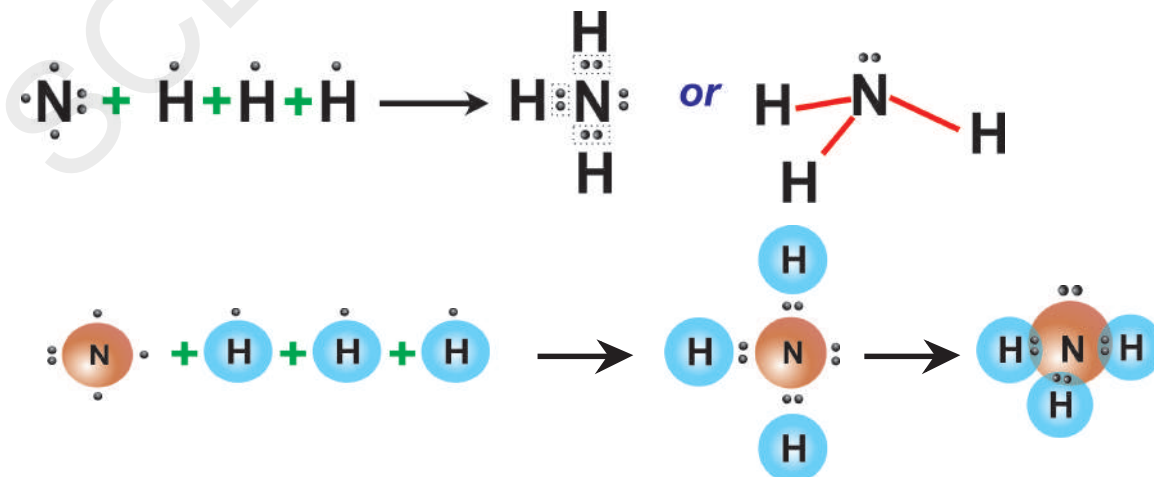


### Ammonia (NH<sub>3</sub>) molecule

In ammonia molecule, three N – H single covalent bonds are present.

Electron configuration of <sub>7</sub>N is 2, 5 and <sub>1</sub>H is 1.

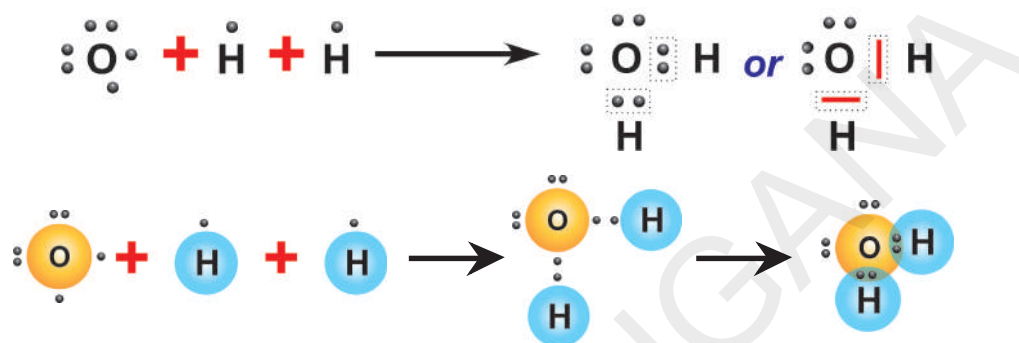
Nitrogen atom contributes three electrons for bonding. Three hydrogen atoms at the same time contribute one electron each for bonding. Six electrons form three pairs and each pair is shared between nitrogen and one hydrogen atom as shown below:



## Water (H<sub>2</sub>O) molecule

In water molecule (H<sub>2</sub>O), there are two O – H single covalent bonds. Electron configuration of  ${}_8\text{O}$  is 2,6 and  ${}_1\text{H}$  is 1.

Oxygen atom needs '2' electrons to attain octet in its valence shell. Therefore it shares '2' electron with two hydrogen atoms to form water (H<sub>2</sub>O) molecule.



The total number of covalent bonds that an atom of an element forms is called its 'covalency'.

## The Bond lengths and Bond energies of covalent bonds

Bond length or bond distance is the equilibrium distance between the nuclei of two atoms which form a covalent bond.

It is generally given in *nm* (nanometer) or  $\text{\AA}$  (Angstrom unit).

Bond energy or Bond dissociation energy is the energy needed to break a covalent bond between two atoms of a diatomic covalent compound in its gaseous state.

### **(?) Do you know?**

- An angstrom ( $\text{\AA}$ ) is a unit of length equal to  $10^{-10}$  metre, or 0.1 nanometre, or 100 picometre.
- 1 nanometre =  $10^{-9}$  metre

## Draw backs of electronic theory of valence

1) When a covalent bond is formed between any two atoms, irrespective of the nature of the atoms, the bond lengths and bond energies are expected to be the same. This is because any covalent bond between any two atoms is a result of mere sharing of two identical electrons. But, practically it was observed that bond lengths and bond energies are not same when the atoms that form the bond are different. (See table - 3)

- What do you understand from bond lengths and bond energies?



- Are the values not different for the bonds between different types of atoms?

2) The theory could not explain why  $\angle \text{BeCl}_2$  is  $180^\circ$ ,  $\angle \text{BF}_3$  is  $120^\circ$ ,  $\angle \text{CH}_4$  is  $109^\circ 28'$ ,  $\angle \text{NH}_3$  is  $107^\circ 48'$  and  $\angle \text{H}_2\text{O}$  is  $104^\circ 31'$  etc.

i.e., it fails to explain the shapes of the molecules.

### Valence shell electron pair repulsion theory

To explain the bond angles in the molecules with three or more than three atoms with all atoms attached to a central atom through covalent bonds a theory called the *valence – shell – electron – pair repulsion – theory*

(VSEPR) was proposed by Sidgwick and Powell (1940). It was further improved by Gillespie and Nyholm (1957).

This theory suggests the following points.

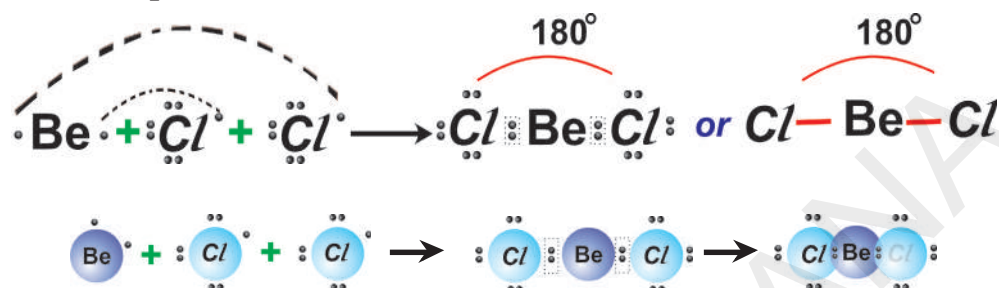
1. VSEPR considers electrons in the valence shells which are in covalent bonds and in lone pairs as charge clouds that repel one another and stay as far apart as possible. This is the reason why molecules get specific shapes.
2. If we know the total number of electron pairs in the valence shell as covalent bonds and lone pairs in the central atom, it will help us to predict the arrangement of those pairs around the nucleus of the central atom and from that the shape of the molecule.
3. Lone pairs occupy more space around the central atom than bond pairs. Lone pair means unshared electron pair or non-bonding electron pair. These are attracted to only one nucleus whereas the bond pair is shared by two nuclei. Thus, the presence of lone pairs on the central atom causes slight distortion of the bond angles from the expected regular shape. If the angle between lone pair and bond pair increases at the central atom due to more repulsion, the actual bond angles between atoms must be decreased.

Table – 3

Bond	Bond length ( $\text{\AA}$ )	Bond (dissociation) energy ( $\text{KJmol}^{-1}$ )
H – H	0.74	436
F – F	1.44	159
Cl – Cl	1.95	243
Br – Br	2.28	193
I – I	2.68	151
H – F	0.918	570
H – Cl	1.27	432
H – Br	1.42	366
H – I	1.61	298
H – O (of $\text{H}_2\text{O}$ )	0.96	460
H – N (of $\text{NH}_3$ )	1.01	390
H – C (of $\text{CH}_4$ )	1.10	410

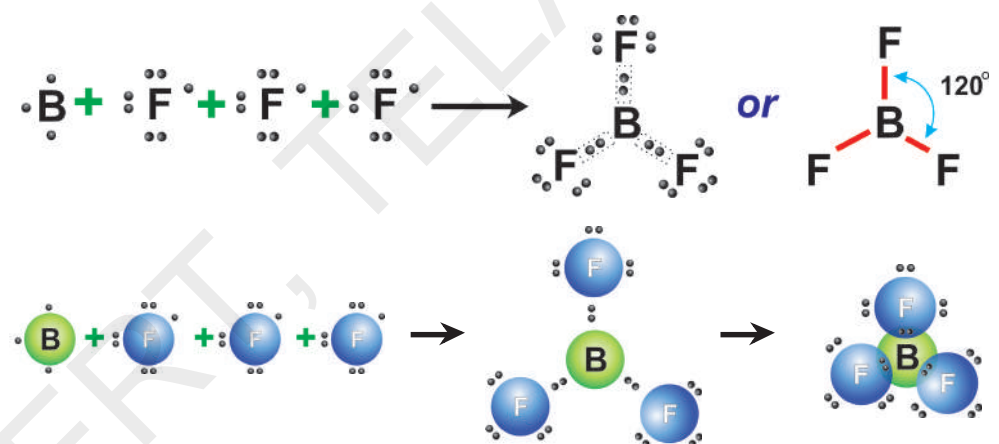
4.1) If two bond pairs are present in two covalent bonds around the nucleus of the central atom without any lone pairs in the valence shell, they must be separated by  $180^\circ$  to have minimum repulsion between them. Thus, the molecule would be linear.

**Example:**



4.2) If three bond pairs are there in three covalent bonds around the nucleus of the central atom, without any lone pairs they get separated by  $120^\circ$  along three corners of a triangle. Therefore, the shape of the molecule is trigonal-planar.

**Example:**

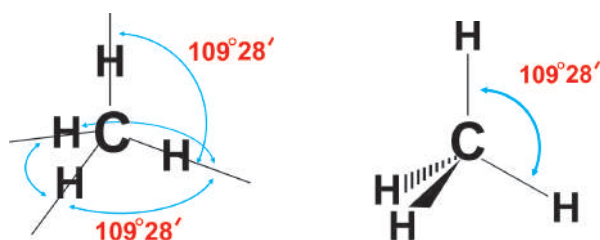


**NOTE:** Did you notice that in  $\text{BeCl}_2$  and  $\text{BF}_3$  the central atoms Be and B did not possess 8 electrons around them in the valence shell. They have only 4 and 6 electrons respectively. These molecules are known as electron deficient molecules.

4.3) If there are four bond pairs in the valence shell of the central atom, the four bond pairs will orient along the four corners of a tetrahedron (three dimensional arrangement) and the bond angle expected is  $109^\circ 28'$

**Example: Methane.**

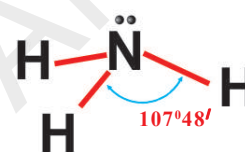
In methane molecule ( $\text{CH}_4$ ),  $\text{H}\hat{\text{C}}\text{H}$  is  $109^\circ 28'$  because of four electron pairs (bonding) around carbon, as shown below:



4.4) If there are three bond pairs and one lone pair i.e., unshared electron pair, then the lone pair occupies more space around the nucleus of the central atom. The remaining three bond pairs come relatively closer as in  $\text{NH}_3$  molecule.

**Example:** Ammonia

In ammonia ( $\text{NH}_3$ ) molecule, there are three bond pairs in covalent bonds (3 N – H) around the nucleus of the nitrogen atom and one lone pair. Lone pair – bond pair repulsion is greater than bond pair – bond pair repulsion. Therefore,  $\text{NH}_3$  which is expected to be tetrahedral with four electron pairs in the valence shell and  $\hat{\text{H}}\text{N}\hat{\text{H}} = 109^\circ 28'$ , it has  $\hat{\text{H}}\text{N}\hat{\text{H}} = 107^\circ 48'$  due to the more repulsion by lone pair on the bond pairs.

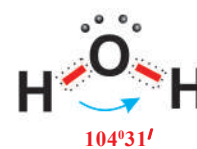


The shape of the  $\text{NH}_3$  molecule is trigonal pyramidal with N at the apex of the pyramid.

4.5) If there are two bond pairs and two lone pairs of electrons around the nucleus of the central atom in its valence shell, lone pair – lone pair repulsion is greater than lone pair – bond pair repulsion. Therefore, the angle between bond pairs further decreases.

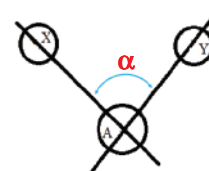
**Example:** Water

In water molecule, ( $\text{H}_2\text{O}$ ) there are four electron pairs around the nucleus of oxygen atom, but, two of them are lone pairs and two bond pairs. Therefore,  $\text{H}_2\text{O}$  molecule gets 'V' shape or bent shape or angular instead of tetrahedral shape as that of  $\text{CH}_4$  due to lone pair – lone pair and lone pair – bond pair repulsions.  $\hat{\text{H}}\text{O}\hat{\text{H}}$  is  $104^\circ 31'$ .



- What is the bond angle in a molecule?

It is the angle subtended by two imaginary lines that pass from the nuclei of two atoms which form the covalent bonds with the central atom through the nucleus of the central atom at the central atom. (see figure ' $\alpha$ ' is the bond angle).



Valence Shell Electron Pair Repulsion Theory (VSEPR) mainly fails in explaining the strengths of the bonds. This is because; the theory still depends on the Lewis concept of covalent bond formation. It could not say anything extra about the electronic nature of covalent bonds.

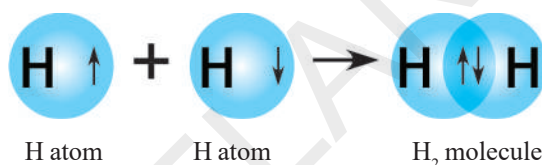
To describe covalent bonding, a quantum mechanical model called *valence bond theory* has been suggested by Linus Pauling (1954).

### Valence bond theory

To describe covalent bonding, a quantum mechanical model called *valence bond theory* has been suggested by Linus Pauling (1954). It is explained as follows:

1. A covalent bond between two atoms is formed when the two atoms approach each other closely and one atom overlaps its valence orbital containing unpaired electron, the valence orbital of the other atom that contains the unpaired electron of opposite spin. The so formed paired electrons in the overlapping orbitals are attracted to the nuclei of both the atoms. This bonds the two atoms together.

Eg: In the formation of  $H_2$  molecule, the  $1s$  orbital of one 'H' atom containing an unpaired electron overlaps the ' $1s$ ' orbital of the other 'H' atom containing unpaired electron of opposite spin giving H-H bond and  $H_2$  molecule.

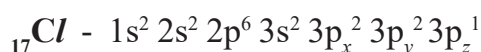


2. The greater the overlapping of the orbitals that form the bond, the stronger will be the bond. This gives a directional character to the bond when other than 's' orbitals are involved.

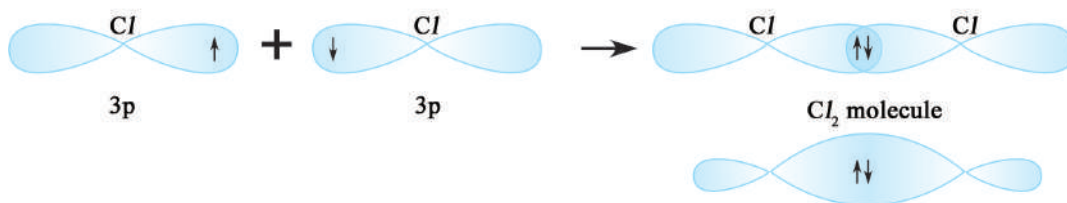
3. Each bonded atom maintains its own atomic orbitals but the electron pair in the overlapping orbitals is shared by both the atoms involved in the overlapping.

4. If two atoms form multiple bonds between them the first bond is due to the overlap of orbitals along the inter-nuclear axis giving a stronger sigma ( $\sigma$ ) bond. After formation of ( $\sigma$ ) bond the other bonds are formed due to the overlap of orbitals side wise or laterally giving weaker  $\pi$  bonds. The ' $\sigma$ ' bond is stronger because the electron pair shared is concentrated more between the two nuclei due to end-end or head on overlap and attracted to both the nuclei. The  $\pi$  bond overlap gives a weaker bond due to the lateral overlap of 'p' orbitals which is not to greater extent.

### Consider Cl-Cl molecule



In the formation of  $Cl_2$  molecule, the  $3p_z$  orbital of one chlorine atom containing an unpaired electron overlaps the  $3p_z$  orbital of other chlorine atom that contains unpaired electron of opposite spin.

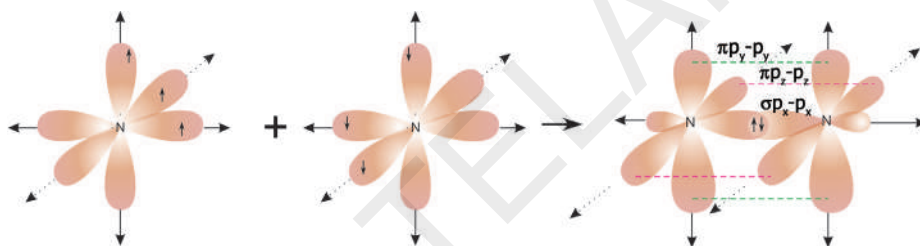


- How is HCl molecule formed?

The '1s' orbital of 'H' atom containing unpaired electron overlaps the '3p' orbital of chlorine atom containing unpaired electron of opposite spin.

### Formation of N<sub>2</sub> molecule

${}^7\text{N}$  has electronic configuration  $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$ . Suppose that  $p_x$  orbital of one 'N' atom overlaps the ' $p_x$ ' orbital of the other 'N' atom giving  $\sigma p_x - p_x$  bond along the inter-nuclear axis. The  $p_y$  and  $p_z$  orbitals of one 'N' atom overlap the  $p_y$  and  $p_z$  orbital of other 'N' atom laterally, respectively perpendicular to inter-nuclear axis giving  $\pi p_y - p_y$  and  $\pi p_z - p_z$  bonds. Therefore, N<sub>2</sub> molecule has a triple bond between two nitrogen atoms.



### Formation of O<sub>2</sub> molecule

${}^8\text{O}$  has electronic configuration  $1s^2 2s^2 2p_x^2 2p_y^1 2p_z^1$ . If the ' $p_y$ ' orbital of one 'O' atom overlaps the ' $p_y$ ' orbital of other 'O' atom along the inter-nuclear axis, a sigma  $p_y - p_y$  bond ( $\sigma p_y - p_y$ ) is formed.  $p_z$  orbital of one 'O' atom overlaps the  $p_z$  orbital of other 'O' atom laterally, perpendicular to the inter-nuclear axis giving a  $\pi p_z - p_z$  bond. O<sub>2</sub> molecule has a double bond between two oxygen atoms.

## Valence bond theory-Hybridisation

### Formation of BeCl<sub>2</sub> (Beryllium chloride) molecule

${}^4\text{Be}$  has electronic configuration  $1s^2 2s^2$ . It has no unpaired electrons. It is expected not to form covalent bonds, but it forms two covalent bonds one each with two chlorine atoms. To explain this, an excited state is suggested for Beryllium in which an electron from '2s' shifts to  $2p_x$  level.

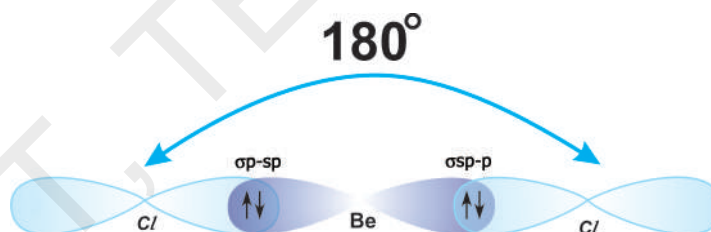
Electronic configuration of  ${}^4\text{Be}$   $1s^2 2s^1 2p_x^1$  and  ${}_{17}\text{Cl}$   $1s^2 2s^2 2p^6 3s^2 3p_x^2 3p_y^2 3p_z^1$

If Be forms two covalent bonds with two chlorine atoms, one bond should be  $\sigma_{2s-3p}$  due to the overlap of '2s' orbital of Be, the ' $3p_z$ ' orbital of one chlorine atom and the other bond should be  $\sigma_{2p-3p}$  due to the overlap of ' $2p_x$ ' orbital of Be atom the 3p orbital of the other chlorine atom. As the orbitals overlapping are different, the bond strengths of two Be-Cl must be different. But, both bonds are of same strength and  $\angle \text{ClBeCl}$  is  $180^\circ$ . To explain the discrepancies like this a phenomenon called 'hybridisation of atomic orbitals' was proposed by Linus Pauling (1931).

**Hybridisation** is a phenomenon of intermixing of atomic orbitals of almost equal energy which are present in the outer shells of the atom and their reshuffling or redistribution into the same number of orbitals but with equal properties like energy and shape.

Be atom in its excited state allows its 2s orbital and  $2p_x$  orbital which contain unpaired electrons to intermix and redistribute to two identical orbitals. As per Hund's rule each orbital gets one electron. The new orbitals based on the types of orbitals that have undergone hybridisation are called sp orbitals. The two sp orbitals of Be get separated by  $180^\circ$ . Now, each chlorine atom comes with its  $3p_z^1$  orbital and overlaps it the sp orbitals of Be forming two identical Be-Cl bonds ( $\sigma_{sp-p}$  bonds).  $\angle \text{ClBeCl} = 180^\circ$ .

Both the bonds are of same strength.



**Beryllium Chloride**

### Formation of $\text{BF}_3$ molecule

${}^5\text{B}$  has electronic configuration  $1s^2 2s^2 2p_x^1$ .

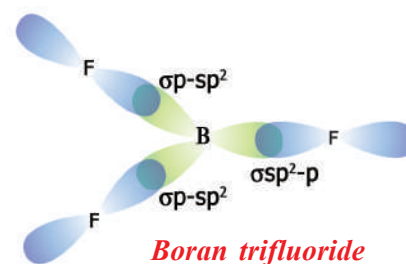
As it has one unpaired electron ( $2p_x^1$ ) it should form only one covalent bond to give B-F molecule. But we get practically  $\text{BF}_3$  molecule.

To explain this, it is suggested that,

i. Boron (B) first undergoes excitation to get electronic configuration  $1s^2 2s^1 2p_x^1 2p_y^1$ .

ii. As it forms three identical B-F bonds in  $\text{BF}_3$ , it is suggested that excited 'B' atom undergoes hybridisation. There is an intermixing of 2s,  $2p_x$ ,  $2p_y$  orbitals and their redistribution into three identical orbitals called  $sp^2$  hybrid orbitals. For three  $sp^2$  orbitals to get separated to have minimum

repulsion the angle between any two orbitals is  $120^\circ$  at the central atom and each  $sp^2$  orbital gets one electron. Now three fluorine atoms overlap their  $2p_z$  orbitals containing unpaired electrons ( $F, 1s^2 2s^2 2p_x^2 2p_y^2 2p_z^1$ ) the three  $sp^2$  orbitals of 'B' that contain unpaired electrons to form three  $\sigma sp^2-p$  bonds.



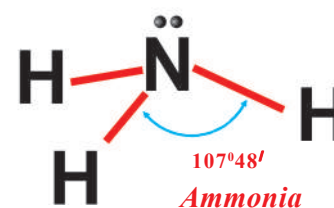
### Formation of $NH_3$ molecule

One nitrogen atom and three hydrogen atoms are present in one ammonia molecule. All the three N-H bonds are of same strength and  $\hat{H}NH = 107^\circ 48'$

${}_7N$  has electronic configuration  $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$ .

If three hydrogen atoms overlap their  $1s$  orbitals on the three 'p' orbitals of nitrogen atom, they give identical  $\sigma p-s$  bonds but, then the  $\hat{H}NH$  should be equal to  $90^\circ$  where as  $107^\circ 48'$ . To explain the discrepancy in the bond angle 'N' atom is said to undergo  $sp^3$  hybridisation.

In this process ' $2s$ ' and  $2p_x, 2p_y, 2p_z$  orbitals of nitrogen intermix and redistribute into four identical  $sp^3$  orbitals. One of the four  $sp^3$  orbitals get a pair of electrons and the other three  $sp^3$  orbitals get one electron each. Now hydrogen atoms overlap their  $1s$  orbitals containing unpaired electrons the  $sp^3$  orbitals of 'N' atom containing unpaired electrons to give three  $\sigma s-sp^3$  bonds.  $\hat{H}NH$  should be  $109^\circ 28'$  for  $sp^3$  hybridisation. As there is a lone pair in one of the  $sp^3$  orbitals, there is a greater lone pair – bond pair repulsion which decreases the bond angle  $\hat{H}NH$  to  $107^\circ 48'$ .



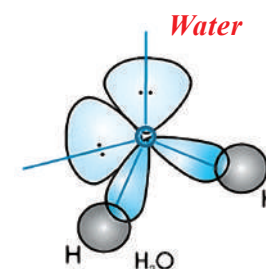
### Shape of water molecule

It is found that  $\hat{H}OH$  is  $104^\circ 31'$ .

The electronic configuration of  ${}_8O$  is  $1s^2 2s^2 2p_x^2 2p_y^1 2p_z^1$  and  ${}_1H$  is  $1s^1$ .

Therefore, there should be two  $\sigma s-p$  bonds due to the overlap of 's' orbitals of two hydrogen atoms, the 'p' orbitals of oxygen atom which contain unpaired electrons.  $\hat{H}OH$  should be  $90^\circ$ .

But  $\hat{H}OH$  observed is  $104^\circ 31'$ . To explain this,  $sp^3$  hybridisation is suggested for the valence orbitals of 'O' atom. One s-orbital ( $2s$ ) and three 'p' orbitals ( $2p_x, 2p_y, 2p_z$ ) intermix and redistribute into four identical  $sp^3$  orbitals. As there are six electrons and two  $sp^3$  orbitals get pairs and two  $sp^3$  orbitals get one electron each. Now, the two  $sp^3$  orbitals of 'O' atom overlap



the 's' orbitals of two hydrogen atoms to give  $\sigma_{sp^3-s}$  bonds. Due to the lone pair – lone pair repulsions and lone pair – bond pair repulsions  $\hat{H}\hat{O}\hat{H}$  decreases from  $109^\circ 28'$  (expected for  $sp^3$  – tetrahedral hybridisation) to  $104^\circ 31'$ .

$CH_4$ ,  $C_2H_4$  and  $C_2H_2$  molecules and their structures will be explained in carbon and its compounds chapter later in this class.

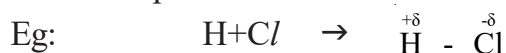
### Properties of ionic and covalent compounds

Table -4

S.No	Property	NaCl (ionic)	HCl (polar covalent)	$C_2H_6$ (covalent)
1.	Formula mass	58.5	36.5	30.0
2.	Physical appearance	White crystalline solid	Colourless gas	Colourless gas
3.	Type of bond	Ionic	Polar covalent	Covalent
4.	Melting point	$801^\circ C$	$-115^\circ C$	$-183^\circ C$
5.	Boiling point	$1413^\circ C$	$-84.9^\circ C$	$-88.63^\circ C$
6.	Solubility	Soluble in polar solvents like water and insoluble in non-polar solvents	Soluble in polar solvents like water and to some extent in non-polar solvents	Soluble in non-polar solvents but insoluble in polar solvents like water
7.	Chemical activity	Highly reactive in polar solvents and reactions are instantaneous	Moderately reactive	Slow or very slow at room temperature

From the above table we understand that ionic compounds like NaCl are solids at room temperature.

Polar compounds like HCl possess properties like melting point, boiling point, reactivity, solubility etc, between those of ionic compounds and covalent compounds. If the covalent bond is between atoms of two different elements, the shared electron pair shift more towards the atom of more electronegative element. Thus within the molecule the more electronegative atom bears a partial negative charge and the less electronegative atom bears a partial positive charge. A molecule of this type which is neutral but possesses partial charges on the atoms within the molecule is called a polar molecule and the bond is called a polar covalent bond or partial ionic and partial covalent bond.



In ionic compounds there exist stronger electrostatic forces of attractions between the oppositely charged ions of these compounds. Therefore, they are solids with high melting points and boiling points. Based



on the principle “like dissolves in like”, they being highly polar, soluble in polar solvents. In chemical reaction of solution of ionic compounds simply rearrangement of ions take place in the solutions, the reactions are instantaneous or very fast.

The forces of attractions among covalent molecules are weak. Therefore, the covalent compounds are gases or liquid at room temperature. They have low melting points and low boiling points. Based on the principle that “like dissolve in like” these covalent compounds are soluble in non-polar solvents because of non-polar nature of solvent molecules. In chemical reactions of covalent compounds there exist bond breaking and bond forming to get products. There fore, these reactions are moderate or very slow.

‘Like dissolves in like’ means what type of chemical bonds are there in the solute particles that solute could be soluble in that solvent which has the similar type of chemical bonds in its molecules.



### Key words

*Electrons, noble gases, Lewis dot structures, Octet rule, chemical bond, Ionic bond, covalent bond, cation, anion, electrostatic force, electrovalent, polar solvent, non-polar solvent, formation of molecules, ionic compounds, covalent compounds, electro positive character, electro negative character, polar bonds, bonded pair of electrons, lone pairs, bond length, bond energy, shape of the molecule, linear, tetrahedral, properties of ionic and covalent compounds.*



### What we have learnt

- Location of elements in the periodic table helps in predicting the type of bonding that will take place between atoms of the elements.
- Ions are positively or negatively charged particles formed by the loss or gain of electrons respectively.
- The force between any two atoms or a group of atoms that results in the formation of a stable entity is called chemical bond.
- The outer most shell of an atom is called valence shell and electrons in this shell are called valence electrons.
- The gases belonging to ‘O’ group are called noble gases because they are reluctant to combine with other atoms. Except helium all other noble gases have an octet of electron configuration in their valence shells.
- Chemically active elements have an incomplete octet in the valence shells of their atoms.
- The number of valence electrons available in the atoms of elements decides the type of bond formed by the atom of the element.
- Elements which have a tendency to gain electrons for attaining octet in their valence shell are called with more electro negative character. They form anions.

- In the formation of ionic bond the atoms of electro positive elements lose their valence electrons to atoms of electro negative elements so that both of them can attain octet in their valence shells.
- The electrostatic attractive force that keeps cation and anion together to form a new electrically neutral entity is called an ionic bond.
- Ionic compounds are often crystalline solids with high melting points.
- A chemical bond that formed by sharing of valence-shell electrons between the atoms so that both of them can attain octet or duplet in their valence shells is called covalent bond.
- A single covalent bond is formed when two atoms share a pair of electrons
- Each shared pair of electrons is equivalent to one covalent bond.
- Electrons are not always shared equally between the atoms in a covalent bond. This leads to bond polarity.
- To explain the strengths of covalent bonds valence band theory is discussed.

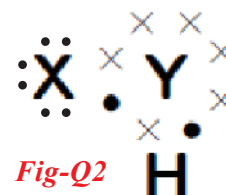


### Improve your learning



#### Reflections on concepts

1. Explain the difference between the valence electrons and the co-valency of an element. (AS<sub>1</sub>)
2. Which chemical compound has the following Lewis notation: (AS<sub>1</sub>)
  - a) How many valence electrons does element Y have?
  - b) What is the valency of element Y?
  - c) What is the valency of element X?
  - d) How many covalent bonds are there in the molecule?
  - e) To which groups the elements X and Y belong? (AS<sub>2</sub>)
3. How bond energies and bond lengths of molecule help us in predicting their chemical properties? Explain with examples. (AS<sub>1</sub>)
4. Draw simple diagrams to show the arrangement of valence electrons in the following compounds: (AS<sub>5</sub>)
  - a) Calcium oxide (CaO)
  - b) Water (H<sub>2</sub>O)
  - c) Chlorine (Cl<sub>2</sub>)
5. Represent each of the following atoms using Lewis notation: (AS<sub>5</sub>)
  - a) beryllium
  - b) calcium
  - c) lithium
  - d) bromine (Br<sub>2</sub>)
  - e) calcium chloride (CaCl<sub>2</sub>)
  - f) carbon dioxide (CO<sub>2</sub>)



#### Application of Concepts

1. Explain the formation of sodium chloride and calcium oxide on the basis of the concept of electron transfer from one atom to another atom. (AS<sub>1</sub>)
2. A, B, and C are three elements with atomic numbers 6, 11 and 17 respectively.
  - i. Which of these cannot form ionic bond? Why? (AS<sub>1</sub>)
  - ii. Which of these cannot form covalent bond? Why? (AS<sub>1</sub>)
  - iii. Which of these can form ionic as well as covalent bonds? (AS<sub>1</sub>)

- How does Lewis dot structure helps in understanding bond formation between atoms? (AS<sub>1</sub>)
- Explain the formation of the following molecules using valence bond theory
  - N<sub>2</sub> molecule
  - O<sub>2</sub> molecule

### Higher Order Thinking questions

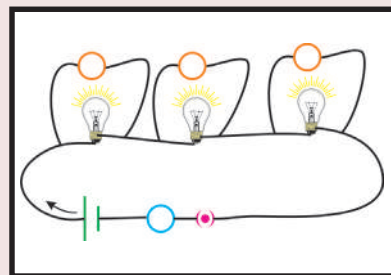
- Two chemical reactions are described below. (AS<sub>5</sub>)
  - Nitrogen and hydrogen react to form ammonia (NH<sub>3</sub>)
  - Carbon and hydrogen bond together to form a molecule of methane (CH<sub>4</sub>).
 For each reaction, give:
  - The valence of each of the atoms involved in the reaction. (AS<sub>1</sub>)
  - The Lewis structure of the product that is formed. (AS<sub>5</sub>)

### Multiple choies questions

- Which one of the following four elements is more electronegative? [     ]
  - Sodium
  - Oxygen
  - Magnesium
  - Calcium
- An element  ${}_{11}\text{X}^{23}$  forms an ionic compound with another element 'Y'. Then the charge on the ion formed by X is [     ]
  - +1
  - +2
  - 1
  - 2
- An element 'A' forms a chloride ACl<sub>4</sub>. The number electrons in the valence shell of 'A' is [     ]
  - 1
  - 2
  - 3
  - 4
- The inert gas element which does not have octet electronic configuration in its outermost orbit is [     ]
  - Helium
  - Argon
  - Krepton
  - Radon
- Number of covalent bonds in methane molecule [     ]
  - 1
  - 2
  - 3
  - 4
- The concept hybridisation of orbitals of an atoms was introduced by [     ]
  - Lives pouling
  - Mosley
  - Lewis
  - Kossel
- The value of bond angle in Berileum chloride molecule is [     ]
  - 180°
  - 120°
  - 110°
  - 104°.31°

### Suggested Projects

- Collect the information about properties and uses of covalent compounds and prepare a report? (AS<sub>4</sub>)



# Electric Current

In previous classes, you had learnt about electric current, battery, electric circuit and its components.

- What do you mean by electric current?
- Which type of charge (positive or negative) flows through an electric wire when it is connected in an electric circuit?
- Is there any evidence for the motion of charge in daily life situations?

In class VIII you learned about lightning. Lightning is an electric discharge between two clouds or between cloud and Earth. This electric discharge through air appears to us as an electric spark or lightning.

Lightning is a live example which provides evidence for the motion of charge in the atmosphere.

- Does motion of charge always lead to electric current?

Let us see.

## Activity 1

**Situation 1:** Take a bulb, a battery, a switch and few insulated copper wires. Connect the ends of the copper wires to the terminals of the battery through the bulb and switch. Now switch on the circuit and observe the bulb.

- What do you notice?

**Situation 2:** Remove the battery from the circuit and connect the remaining components to make a complete circuit. Again switch on the circuit and observe the bulb. Does the bulb glow?

**Situation 3:** Replace the copper wires with nylon wires and connect the nylon wires to the terminals of the battery through a bulb and switch. Now switch on the circuit and observe the bulb. Does the bulb glow?

After doing these activities you will notice that the bulb glows only in situation 1.

- Can you predict the reason for the bulb not glowing in situations 2 and 3?

In class VII, you have learnt that the battery stores chemical energy and this energy converts into electric energy and makes the bulb to glow as you observed in situation 1 i.e. the battery supplies the required energy to make the bulb glow. But in situation 3, though there is a battery in the circuit, the bulb does not glow because the connecting wires (nylon wires) are not able to carry the energy from source (battery) to bulb.

Hence, the nature of the substance plays an important role in the transfer of energy from battery to bulb. The material which transfers energy from battery (source) to the bulb is called a conductor and the material which cannot transfer energy from battery (source) to the bulb is called a non conductor.

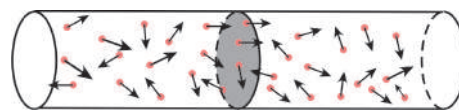
- Why do all materials not act as conductors?
- How does a conductor transfer energy from source to bulb?

Drude and Lorentz, at the beginning of the 20<sup>th</sup> century, proposed that conductors like metals contain a large number of free electrons while the positive ions are fixed in their locations.

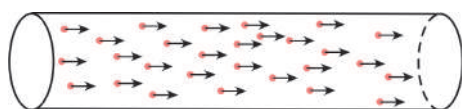
Let us understand the behaviour of these free electrons. Assume that a conductor is an open circuit. The free electrons move randomly in the conductor as shown in fig.- 1. When the electrons are in random motion, they can move in any direction. Hence, if you imagine any cross section as shown in fig.- 1, the number of electrons, crossing the cross section of a conductor from left to right in one second is equal to that of electrons passing the cross section from right to left in one second. It means that net charge moving along a conductor through any cross section is zero when the conductor is in open circuit.

- What happens to the motion of electrons when the ends of the conductor are connected to the battery?

When the ends of the conductor are connected to the battery through a bulb, the bulb glows because energy transfer takes place from battery to the bulb. The electrons are responsible for this transfer of energy. If the electrons are responsible for transfer



*fig-1: Random motion of electrons (in open circuit)*



**fig-2: Ordered motion of electrons**

of energy from battery to bulb, they must have an ordered motion. When the electrons are in ordered motion, there will be a net charge crossing through any cross section of the conductor. See fig.- 2. This

ordered motion of electrons is called electric current.

Thus we can say that electric current is ordered motion of charges.

### Electric current

Electric current is defined as the amount of charge crossing any cross section of the conductor in one second.

Let  $Q$  be the charge crossing through any cross section of the conductor in a time interval  $t$ . Then the amount of charge crossing through that cross

section in one second is  $\frac{Q}{t}$ . Therefore,

Electric current = electric charge/time interval

$$I = \frac{Q}{t}$$

The SI unit of electric current is ampere denoted by A.

1 Ampere = 1 Coulomb/1 Second (1 Coulomb =  $6.625 \times 10^{18}$  electrons)

1 A = 1 C/s

- How can we measure electric current?

Usually an ammeter is used to measure electric current. It is always connected in series to the circuit. We can also use a multimeter by selecting its current measurement setting.

- **Why do electrons move in specified direction?**

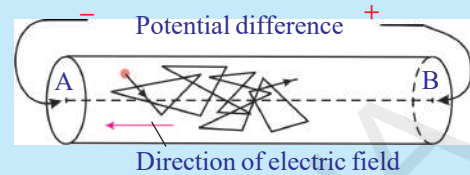
When the conductor is not connected to the circuit through a battery, the electrons inside the conductor are in random motion but when the conductor is connected to a battery, the electrons move in a specified direction.

- In which direction do the electrons move?
- Do the electrons experience force to accelerate continuously?
- Do they move with a constant speed?

The free electrons in the conductor are accelerated towards the positive terminal of the battery and when these electrons are in motion under the

influence of the field, they collide with positive ions, lose energy and may even come to a halt at every collision. They are again accelerated by the electric field and make collisions with other positive ions. In this way they continue to move along the conductor. The motion of electron is shown in fig.-3.

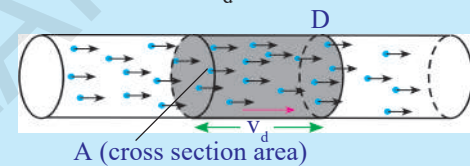
Hence, we assume that electrons in the conductor move with a constant average speed. We call this speed as drift speed or drift velocity.



**fig-3: Motion of electron**

Let us calculate the drift speed of free charges quantitatively.

Consider a conductor with cross sectional area  $A$ . Assume that the ends of the conductor are connected to a battery to make the current flow through it. Let  $v_d$  be the drift speed of the charges as shown in fig.- 4 and  $n$  be the number of charges present in the conductor in a unit volume (charge density). The average distance covered by one charge in one second is  $v_d$ . Then the volume of the conductor for this distance is equal to  $Av_d$  (see fig.- 4). The number of charges contained in that volume is equal to  $nAv_d$ . Let  $q$  be the charge of each carrier. Then the total charge crossing the cross sectional area at position  $D$  in one second is  $nqAv_d$ . This is equal to electric current. Hence,



**fig-4: Drift of positive charges**

$$\text{Electric current } I = nqAv_d \quad \dots\dots\dots (1)$$

$$\text{Therefore, } v_d = \frac{I}{nqA} \quad \dots\dots\dots (2)$$

We know that the charge carriers in a conductor are electrons. The magnitude of electric charge ‘ $e$ ’ is  $1.602 \times 10^{-19}\text{C}$ .

Let us calculate the drift speed of electron in a copper wire carrying a current of 1A and cross sectional area  $A = 10^{-6}\text{m}^2$ . The electron density of copper that was found experimentally is  $n = 8.5 \times 10^{28}\text{m}^{-3}$ . Substituting these values in equation (2) with  $q = e$ , we get,

$$v_d = \frac{1}{(8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 10^{-6})}$$

$$v_d = 7 \times 10^{-5}\text{m/s} = 0.07\text{mm/s}$$

This shows that the electrons are moving very slowly.

When we switch on any electric circuit, irrespective of length of the connecting wire (conductor) an electric field is set up throughout the conductor instantaneously due to the potential difference of the source (battery) connected to the circuit. This electric field makes all the electrons

to move in a specified direction simultaneously.

The equation  $I = nqAv_d$  indicates that the values of  $n$  and  $A$  are positive. The direction of electric current is determined by the signs of the charge  $q$  and drift speed  $v_d$ . For electrons (negative charges),  $q$  is negative and  $v_d$  is positive. Then the product of  $q$  and  $v_d$  is negative. This negative sign shows that the direction of electric current is opposite to the flow of negative charge. For positive charges the product of  $q$  and  $v_d$  is positive. Hence, the direction of electric current can be taken as the direction of flow of positive charges.

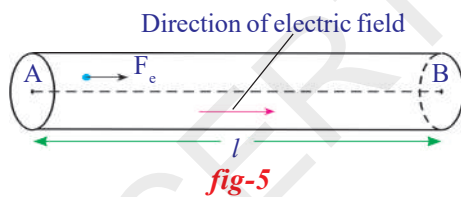
## Potential Difference

- Where do the electrons get energy for their motion from?

When the ends of a conducting wire are connected to the terminals of a battery, an electric field is setup throughout the conductor. This field exerts a force on the charge (electron). Let  $F_e$  be the force exerted by the electric field on a free charge  $q$ . The free charges accelerate in the direction of the electric field (If the free charges are electrons, then the direction of electric force on them is opposite to the direction of electric field). It means the electric field does some work to move free charges in a specified direction.

- Can you find the work done by the electric force?

Let the electric force made the charges move through a distance ' $l$ ' from A to B as shown in fig.- 5. We know that, the work is the product of force and distance along the direction of force.



Hence, work done by the electric force on a free charge  $q$  is given by

$$W = F_e l$$

What is the work done by the electric force on unit charge?

$$\text{Work done by the electric force on unit charge} = \frac{W}{q} = \frac{F_e l}{q}$$

Work done by the electric force on unit positive charge to move it through a distance ' $l$ ' from A to B is called potential difference between those points. Potential difference is denoted by a symbol  $V$ . The potential difference between two points separated by a distance  $l$  in a conducting wire is given by,

$$V = \frac{W}{q} = \frac{F_e l}{q}$$



This potential difference is also called voltage. The SI unit of potential difference is “Volt” and it is denoted by V.

$$1 \text{ Volt} = 1 \text{ Joule}/1 \text{ Coulomb}$$

$$1 \text{ V} = 1 \text{ J/C}$$

- What is the direction of electric current in terms of potential difference?
- Do positive charges move in a conductor? Can you give an example of this?

Let us recall your experience of electrolysis and electroplating and conductivity of fluids that you had learned in earlier classes. When electric current is allowed to pass through fluids, the positive ions (cations) and negative ions (anions) move in opposite directions. The direction of the motion of positive charges in an electrolyte is always in the direction of the electric field while negative charges move in a direction opposite to that of positive charges. Thus for conduction in fluids there exists motion of both positive and negative charges. Whereas in case of metal conductors there will be only motion of electrons. (The positive charges are fixed in the lattice)

If positive charges move from point A to B in a conductor, the electric field does positive work so  $W/q$  is positive for free positive charges. You can say that the direction of the electric field is from A to B and the point A is at high potential and point B is at low potential. As negative charges always move in a direction opposite to the electric field we consider that electrons move from low potential to high potential.

We know that in a battery or cell a constant potential difference is maintained till the battery is completely discharged.

- How does a battery maintain a constant potential difference between its terminals?
- Why does the battery discharge when its positive and negative terminals are connected through a conductor?

To answer this, we need to know about how a battery or a cell works.

A battery consists of two metal plates (electrodes) and a chemical (electrolyte). The electrolyte (chemical) between the two metal plates consists of positive and negative ions which move in opposite directions (see fig.- 6). The electrolyte exerts a certain force on these ions and makes them move in a specified direction. Let us call this force as a chemical force ( $F_c$ ). Depending upon the nature of the chemical, positive ions move towards one of the plates and accumulate on that plate. As a result of this

accumulation of charges on this plate it becomes positively charged (called anode). Negative ions move in a direction opposite to the motion of positive ions and accumulate on the other plate. As a result of this the plate becomes negatively charged (called cathode). This accumulation of different charges on respective plates continues till both plates are sufficiently charged.

But the ions in motion experience another force when sufficient number of charges are accumulated on the plates. Let us call this force as electric force ( $F_e$ ). The direction of this force is opposite to the direction of chemical force  $F_c$  and the magnitude of this force depends on the amount of charge accumulated on the plates.

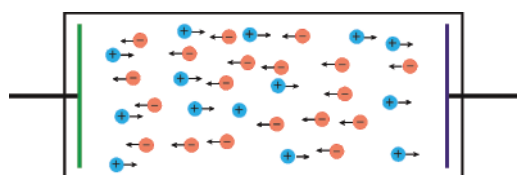


fig-6

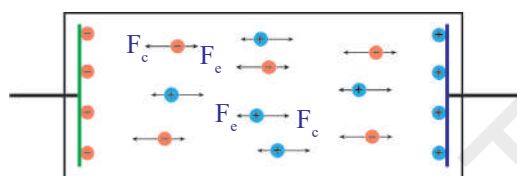


fig-7

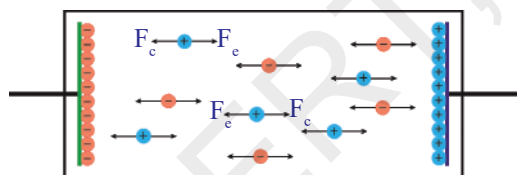


fig-8

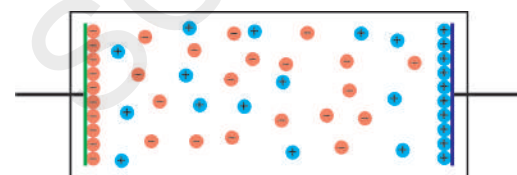


fig-9

The motion of ions continue towards their respective plates if the chemical force  $F_c$  is stronger than electric force  $F_e$ . See fig.- 7. The accumulation of charges on plates is continuous till the electric force  $F_e$  becomes equal to chemical force  $F_c$ . At this situation there will not be any motion in ions due to balance of forces  $F_c$  and  $F_e$ . It is shown in fig.- 8. The new battery that we buy from the shop is at a stage where the ions in the electrolyte are under the influence of balanced forces. See fig.- 9. This is the reason for the constant potential difference between the terminals of a battery.

The amount of charge accumulated on the plates depends on nature of the chemical used in the battery.

- What happens when the battery is connected in a circuit?

When a conducting wire is connected to the terminals of the battery, a potential difference is created between the ends of the conductor. This potential difference sets up an electric field throughout the conductor (the direction of electric field is from positive terminal to negative terminal in the conductor).

We know that the conductor contains large number of electrons. The electrons near

the positive terminal of the battery are attracted by it and start to move towards positive terminal. As a result, the amount of positive charge on this plate decreases. So the electric force  $F_e$  becomes weaker than chemical force  $F_c$  and chemical force pulls negative ions from the positive plate (anode) and makes them move towards the negative plate (cathode). The negative terminal pushes one electron into the conductor because of stronger repulsion between negative terminal and negative ion. Hence, the total number of electrons in the conductor remains constant during the current flow. The above said process continuous till equilibrium is attained between the forces  $F_e$  and  $F_c$ .

### Electromotive force (emf)

When the ends of the conductor are connected to the terminals of a battery, the electrons in the conductor move with a drift speed from negative terminal to positive terminal because of the electric force acting on them. At the same time negative ions of equal amount of charge move from positive terminal to negative terminal against the electric force ( $F_e$ ) because of the chemical force acting on them within battery. Thus, some chemical energy is spent to move ions in the battery. It means that an amount of work is done by the chemical force ( $F_c$ ).

Let us assume that work done by the chemical force to move a negative charge  $q$  from positive terminal to negative terminal against the electric force  $F_e$  be 'W' and also assume that the magnitude of chemical force  $F_c$  is equal to magnitude of electric force ( $F_e$ ).

The work done on negative charge  $q$  by the chemical force,  $W = F_c d$  where 'd' is the distance between the terminals. Then work done by the chemical force to move 1 Coulomb charge from positive terminal to

negative terminal is given by,  $\frac{W}{q} = \frac{F_e d}{q}$ . We know that  $F_c = F_e$ , then we get

$$\frac{W}{q} = \frac{F_e d}{q}$$

This  $\frac{W}{q}$  is the work done by the chemical force on unit negative charge to move it from positive terminal to negative terminal. This is called emf ( $\epsilon$ ).

$$\epsilon = \frac{W}{q} = \frac{F_e d}{q}$$

Generally, emf is defined as the work done by the chemical force to move unit positive charge from negative terminal to positive terminal of the battery.

- How can we measure potential difference or emf?

Generally a volt meter is used to measure potential difference or emf across an electric device like battery. It must be connected in parallel to the electric device to measure the potential difference across the ends of the electric device.

When a battery in a torch is used for several weeks, the light from its bulb becomes dim. We say that the battery or cell in the torch is discharged. What does it mean?

- Is there any relation between emf of battery and drift speed of electrons in the conductor connected to a battery?

### Ohm's law



### Lab Activity

**Aim:** To show that the ratio  $V/I$  is a constant for a conductor.

**Materials required:** 5 dry cells of 1.5V each, conducting wires, an ammeter, a volt meter, thin iron/manganin spoke of length 10cm, LED and key.

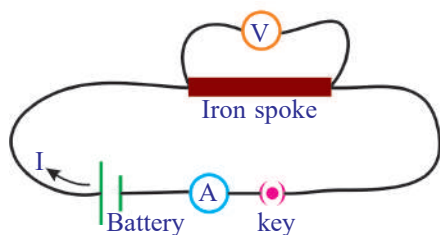


fig-10

**Procedure:** Connect a circuit as shown in fig.-10. Solder the conducting wires to the ends of the iron spoke. Close the key. Note the readings of current from ammeter and potential difference from volt meter in table 1.

Table:1

Sl.No.	Potential difference (V)	Current (I)	$\frac{V}{I}$

Now connect two cells (in series) instead of one cell in the circuit. Note the respective readings of the ammeter and volt meter and record the values in table 1. Repeat the same for three cells, four cells and five cells respectively. Record the values of potential difference (V) and current (I) corresponding to each case in the table 1. Find  $\frac{V}{I}$  for each set of values. What do you notice? The ratio  $\frac{V}{I}$  is a constant. We can write this mathematically as

$$V \propto I$$

From this experiment we can conclude that the potential difference between the ends of the iron spoke (conductor) is directly proportional to the current passing through it (assuming the temperature of the iron spoke is constant during the flow of current through it).

Draw a graph between V and I taking the current (I) along y-axis and potential difference (V) along x-axis with appropriate scale. You will get a straight line graph passing through the origin as shown in fig.- 11.

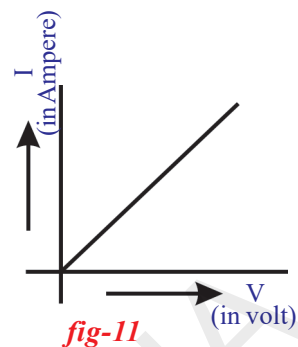


fig-11

Repeat the process by using a LED instead of iron spoke. The long terminal of the LED is connected to the positive terminal of the battery and short terminal of the LED is connected to negative terminal of the battery. Note the values of current 'I' and potential difference 'V' in each case and record the values in table 1 (draw this table in your notebook). Find V/I for each set of values I and V. You will notice that the ratio V/I is not a constant. Draw a graph between V and I for LED. You will get a curved graph as shown in fig.- 12.

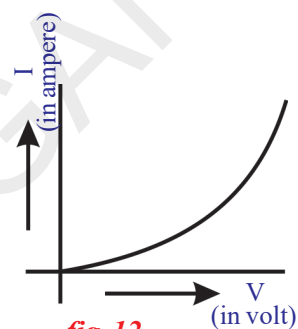


fig-12

From the above lab activity we can conclude that the ratio between V and I is constant for some materials at constant temperature. This fact was established by German Physicist, George Simon Ohm and it is popularly known as Ohm's law.

We can define Ohm's law as follow.

The potential difference between the ends of a conductor is directly proportional to the electric current passing through it at constant temperature.

Let V be the potential difference between the ends of the conductor and I be the current passing through it.

$$V \propto I \text{ (temperature is constant)}$$

$$\frac{V}{I} = \text{Constant}$$

This constant is called resistance of the conductor. It is denoted by 'R'. Then we get  $\frac{V}{I} = R$ .

$$V = IR$$

The SI unit of resistance is Ohm. The symbol of ohm is  $\Omega$ .

$$1 \text{ Ohm} = 1 \text{ Volt}/1 \text{ Ampere}$$

$$1 \Omega = 1 \text{V/A}$$

- Can you guess the reason why the ratio of  $V$  and  $I$  in case of LED is not constant?
- Do all materials obey Ohm's law?
- Can we classify the materials based on Ohm's law?

Based on Ohm's law materials are classified into two categories. Those which obey Ohm's law are called ohmic materials. For example, metals are ohmic materials. Those which do not obey Ohm's law are called non ohmic materials. For example, LEDs are non ohmic materials.

### Limitations of Ohm's Law

Ohm's law is valid for metal conductors provided the temperature and other physical conditions remain constant. The resistance of the material changes with temperature. Hence for changing temperature the  $V$ - $I$  graph for a conductor will be non-linear. Ohm's law is not applicable to gaseous conductors. It is also not applicable to semiconductors such as germanium and silicon.

- What is resistance?
- Is the value of resistance the same for all materials?

When a conductor is connected to a battery the free electrons start moving with a drift speed in a specified direction. During the motion, the electrons collide with positive ions (fixed) of the lattice and come to halt. This means that they lose mechanical energy in the form of heat. Due to the electric field that was set up by the battery throughout the conductor, these electrons regain the energy from the field and proceed to move. The motion of electrons is obstructed by the lattice ions. The obstruction offered to the flow of electrons in a conductor by lattice ions depends upon the nature of the material.

Therefore, the **resistance** of a conductor is defined as the obstruction to the motion of the electrons in a conductor. The material which offers resistance to the motion of electrons is called **resistor**.

- Is there any application of Ohm's law in daily life?
- What causes electric shock in the human body – current or voltage?

Let us see.

### Electric shock

Let us assume that human body is a resistor. The resistance of the human body generally varies from  $100\ \Omega$  (if body is wet with salt water) to  $5,00,000\ \Omega$  (if the skin is very dry). Let us calculate the amount of current that flows through the human body. Let us assume you have touched the two electrodes of a battery of  $24V$  with dry fingers in such a way that the circuit is complete. Let your body resistance be  $1,00,000\ \Omega$ . Then the

current flowing through your body is given by  $I = 24/100000 = 0.00024A$ . This current is very small. When such small current passes through the human body, it does not affect the functioning of various organs inside the body.

- Do you know the voltage of mains that we use in our household circuits?
- What happens to our body if we touch live wire of 240V?

The current passing through our body when we touch a live wire of 240V is given by  $I = 240/100000 = 0.0024A$ . When this quantities of current flows through the body the functioning of organs inside the body gets disturbed. This disturbance inside the body is felt as electric shock. If the current flow continues further, it damages the tissues of the body which leads to decrease in resistance of the body. When this current flows for a longer time, damage to the tissues increases and thereby the resistance of human body decreases further. Hence, the current through the human body will further increase. If this current reaches 0.07A, it effects the functioning of the heart and if this much current passes through the heart for more than one second it could be fatal. If this current flows for a longer time, the person in electric shock is being killed. See the table 2 that describes the effects of electric current on human body.

**Table-2**

Current in ampere	Effect
0.001	Can be felt
0.005	Is painful
0.010	Causes involuntary muscle contractions (spasms)
0.015	Causes loss of muscle control
0.070	If through the heart, causes serious disruption ; probably fatal if current lasts for more than one second

From the above discussions, we can conclude that an electric shock can be experienced when there is a potential difference exists between one part of the body and another part. When current flows through human body, it chooses the path which offers low resistance. The resistance of a body is not uniform throughout it. For example, skin offers more resistance than the organs inside the body. As long as current flow continues inside the body the current and resistance of human body goes on changing inversely. Hence, the electric shock is a combined effect of potential difference, electric current and resistance of the human body.

- Why doesn't a bird get a shock when it stands on a high voltage wire?

There are two parallel transmission lines on electric poles. The potential difference between these two lines is 240V throughout their lengths. If you connect any conducting device across these two wires, it causes current to flow between the wires. When the bird sits on a high voltage wire, there is no potential difference between the legs of the bird because it stands on a single wire. So no current passes through the bird. Hence, it doesn't feel any electric shock.

### **(?) Do you know?**

A multi meter is an electronic measuring instrument that combines several measurement functions in one unit.



Digital multi meter displays the measured value in numerals.

A multi meter has three parts

**Display:** The display usually has four digits and the ability to display a negative sign.

**Selection knob:** The selection knob allows the user to set the multi meter to read different functions such as milliamps (mA) of current, voltage (V) and resistance ( $\Omega$ ).

**Ports:** Multi meters generally have two ports. One is usually labelled as 'COM' (common or ground port). This is where black test lead is connected. The other is labelled as mA/V/ $\Omega$  port where the red lead is conventionally plugged in.

**WARNING:** Most multi meters can measure AC quantities also, but AC circuits can be dangerous. So measure DC quantities only.

## Factors affecting the resistance of a material

### Temperature and resistance

#### Activity 2

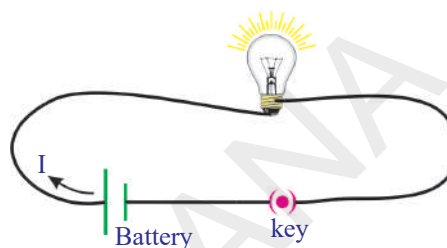
Measure the resistance of the bulb when it is in open circuit using a multi meter. To measure the resistance of a bulb set the multi meter as ohm meter and place the multi meter knob at 20K  $\Omega$ . Now place the leads of the multi meter on the terminals of the bulb. The meter will show one of the following readings.

- 0.00 or 1 or the actual resistance of the bulb.



- If the multi meter reads 1, or displays OL, it's overloaded. You will need to try a higher mode such as 200K  $\Omega$  or 2M  $\Omega$  etc.
- If the multi meter reads 0.00 or nearly 0, then you need to lower the mode to 2K  $\Omega$  or 200  $\Omega$ .

Note the value of resistance in your note book. Connect a circuit with components as shown in fig.- 13. Switch on the circuit. After few minutes, measure the resistance of the bulb again as explained above. Note this value in your note book. What difference do you notice between these two readings? The value of resistance of the bulb in second instance is more than the resistance of the bulb in open circuit.



**fig-13**

- What could be the reason for increase in the resistance of the bulb when current flows through it?

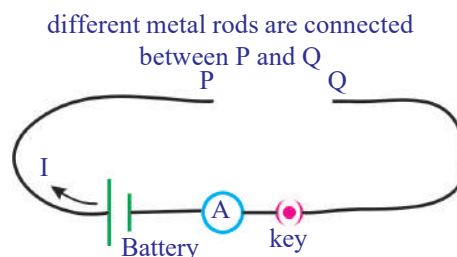
You will notice that the bulb gets heated. The increase in temperature of the filament in the bulb is responsible for increase in resistance of the bulb. Hence we can conclude that there is a relation between resistance of the bulb and its temperature.

Thus the value of resistance of a conductor depends on temperature and increases with rise in temperature.

### Nature of material and resistance

#### Activity 3

Collect different metal rods of the same length and same cross sectional area like copper, aluminium, iron etc. Make a circuit as shown in fig.- 14. P and Q are the free ends of the conducting wires. Connect one of the metal rods between the ends P and Q. Switch on the circuit. Measure the electric current using the ammeter connected to the circuit and note it in your notebook. Repeat this with other metal rods and measure electric currents in each case. What do you notice? The values of current are different for different metal rods for a constant potential difference.



**fig-14**

From this activity, we conclude that the resistance of a conductor depends on the material of the conductor.

- What happens to the resistance of a conductor if we increase its length?

Let us find out.

### Length of the conductor and resistance

#### Activity 4

Collect iron spokes of different lengths with the same cross sectional areas. Make a circuit as shown in fig.- 14. Connect one of the iron spokes, say 10cm length, between P and Q. Measure the value of the current using the ammeter connected to the circuit and note the value in your note book. Repeat this for other lengths of the iron spokes. Note corresponding values of currents in your note book. What do you notice? The current decreases with increase in the length of the spoke. Thus the resistance of each spoke increases with increase in the length for a constant potential difference.

From this activity, we can conclude that the resistance ( $R$ ) of a conductor is directly proportional to its length ( $l$ ) for a constant potential difference.

i.e.

$$R \propto l \quad (\text{at constant temperature and cross sectional area})$$

..... (1)

- Does the thickness of a conductor influence its resistance?

Let us find out.

### Crosssection area and resistance

#### Activity 5

Collect iron rods of equal lengths but different cross section areas. Make a circuit as shown in fig.- 14. Connect one of the rods between points P and Q. Note the value of the current using the ammeter connected to the circuit and note it in your note book. Repeat this with other rods. Note the corresponding values of currents in each case and note them in your note book. You will notice that the current flowing through the rod increases with increase in its cross sectional area. Hence, the resistance of a rod decreases with increase in the cross section area of the rod.

From this activity, we conclude that the resistance of a conductor is inversely proportional to its cross section area.

i.e.

$$R \propto \frac{1}{A} \quad (\text{at constant temperature and length of the conductor})$$

..... (2)

From the equations (1) and (2), we get

$$R \propto \frac{l}{A} \quad (\text{at constant temperature})$$

$$R = \frac{\rho l}{A}$$

Where,  $\rho$  is a proportionality constant and it is called specific resistance or resistivity. See fig.- 15 to get clear picture of this equation.

Specific resistance depends on the temperature and nature of the material where as the resistance of the conductor depends on nature of material, temperature and geometrical factors like length and cross section area of the conductor.

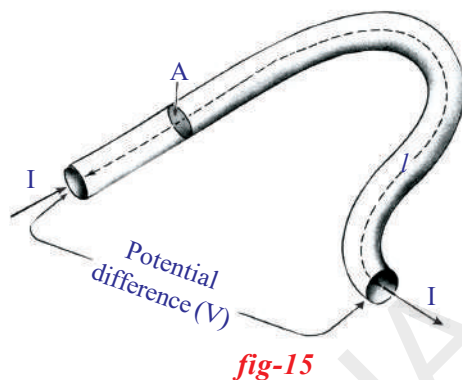
The SI unit of resistivity is  $\Omega \cdot \text{m}$ .

The reciprocal of resistivity is called conductivity ( $\sigma$ ).

The values of resistivity of material determine their conductivity.

Metals with low resistivity behave as good conductors. Metals such as copper are therefore used for making electric wires. The filament of an electric bulb is usually made of tungsten, because of its higher resistivity values and melting point ( $3422^\circ\text{C}$ ).

The values of resistivity of insulators are very high of the order of  $10^{14}$  to  $10^{16} \Omega\cdot\text{m}$ . Alloys like Nichrome (Nickel, chromium and iron) and Manganin (86% copper, 12% manganese, 2% nickel) have 30-100 times larger values of resistivity than those of metals. This makes them suitable for use in the heating elements of electric irons, toasters etc. These alloys also have the advantage that their resistance varies very little with temperature and they do not oxidise easily. The resistivity of materials such as silicon and germanium are  $10^5$  to  $10^{10}$  times more than that of metals, but  $10^{15}$  to  $10^{16}$  times less than that of insulators. Such materials are called semiconductors. Semiconductors are used to make diodes, transistors and integrated Circuits (ICs). ICs are used in all sorts of electronic devices, including computer, TV, mobile phones etc.



**Table 3**  
**Resistivity of various materials**

Material	$\rho(\Omega\cdot\text{m})$ at $20^\circ\text{C}$
Silver	$1.59 \times 10^{-8}$
Copper	$1.68 \times 10^{-8}$
Gold	$2.44 \times 10^{-8}$
Aluminium	$2.82 \times 10^{-8}$
Calcium	$3.36 \times 10^{-8}$
Tungsten	$5.60 \times 10^{-8}$
Zinc	$5.90 \times 10^{-8}$
Nickel	$6.99 \times 10^{-8}$
Iron	$1.00 \times 10^{-7}$
Lead	$2.20 \times 10^{-7}$
Nichrome	$1.10 \times 10^{-6}$
Carbon (Graphite)	$2.50 \times 10^{-6}$
Germanium	$4.60 \times 10^{-1}$
Drinking water	$2.00 \times 10^{-1}$
Silicon	$6.40 \times 10^2$
Wet wood	$1.00 \times 10^3$
Glass	$10.0 \times 10^{10}$
Rubber	$1.00 \times 10^{13}$
Air	$1.30 \times 10^{16}$

- How are electric devices connected in circuits?

## Electric Circuits

A closed path created by the connecting wires through a battery along which electrons can flow is called a circuit. For a continuous flow of electrons in the circuit it must be a complete circuit with no gaps left in between. Usually a gap is provided in the circuit by an electric switch that can be opened or closed to either cut off or allow current flow through the circuit. Circuits may have more than one device (called as component) that receives electric energy from the source. These devices are commonly connected in the circuit either in series or in parallel.

When the components of the circuit are connected in series, there will be a single path for flow of electrons between the terminals of the battery, generator or wall socket (which is simply an extension of these terminals). When these components are connected in parallel, they form branches and each branch provides a separate path for the flow of electrons.

Both the series and parallel connections have their own distinctive characteristics. We shall briefly study circuits, using these two types of connections.

### Series connection of resistors

#### Activity 6

Take different bulbs. Measure their resistances with a multi meter. Note their values in your book as  $R_1, R_2, R_3$ .

Connect them as shown in fig.- 16.

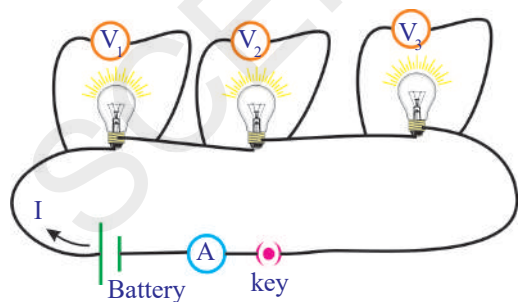


fig-16

Measure the potential difference between terminals of the battery connected to the circuit. Measure the potential differences between the ends of each bulb and note them as  $V_1, V_2$  and  $V_3$  from voltmeters in your note book. Compare the potential difference of the battery and resistors.

- What do you notice?

The sum of the potential differences of the bulbs is equal to potential difference across the combination of the resistors. Then we get,

$$V = V_1 + V_2 + V_3 \quad \dots\dots\dots (1)$$

Measure the value of the current flowing in the circuit with help of the ammeter. Note its values in your book as  $I$ .

- What do you notice?

### Equivalent resistance of a series connection:

Observe fig.- 17. In this fig.- the bulbs are shown as resistors with symbols.

In series connection of resistors there is only one path for the flow of current in the circuit. Hence, the current in the circuit is equal to  $I$ .

According to Ohm's law,

Potential difference across  $R_1$  is,  $V_1 = IR_1$

Potential difference across  $R_2$  is,  $V_2 = IR_2$

Potential difference across  $R_3$  is,  $V_3 = IR_3$

Let  $R_{eq}$  is the equivalent resistance of the combination of resistors in series.

- What do you mean by equivalent resistance?

If the current drawn by a resistor is equal to the current drawn by the combination of resistors then the resistor is called as equivalent resistor (provided the source in the circuit is constant).

So, we have  $V = IR_{eq}$

Substituting the values of  $V_1, V_2, V_3$  and  $V$  in the equation (1), we get

$$IR_{eq} = IR_1 + IR_2 + IR_3$$

$$R_{eq} = R_1 + R_2 + R_3$$

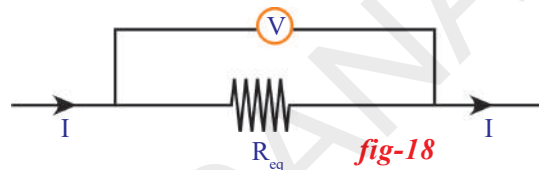
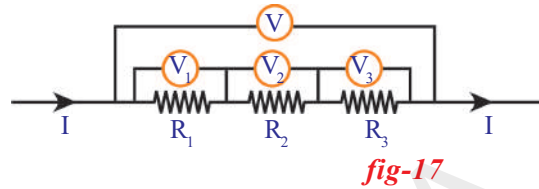
From the above equation you can conclude that the sum of individual resistances is equal to their equivalent resistance when the resistors are connected in series.

- What happens when one of the resistors in series breaks down?

When one of the resistors in series breaks down, the circuit becomes open and flow of current cannot take place in the circuit. This is the reason why household electrical appliances are not connected in series.

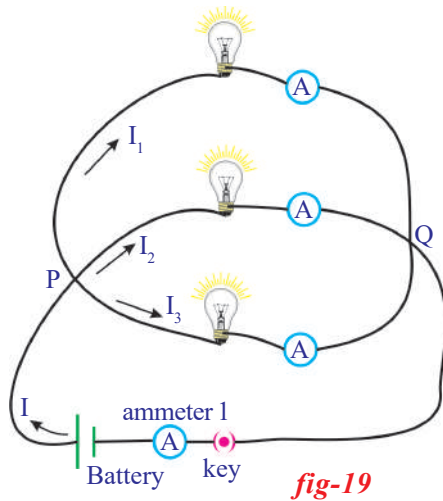
- Can you guess in what way household wiring has been done?

Let us see



## Parallel Connection of resistors

### Activity 7



Use the bulbs used in activity 6 and connect these bulbs as shown in fig.- 19.

Measure the potential difference across each bulb using a voltmeter or multi meter. Note these values in your note book. What do you notice? The potential difference at the ends of each bulb is the same. These bulbs are said to be in parallel connection. Measure electric currents flowing through each bulb using ammeters. Note these values.

Let  $I_1, I_2$  and  $I_3$  be the currents flowing through  $R_1, R_2$  and  $R_3$  resistors respectively.

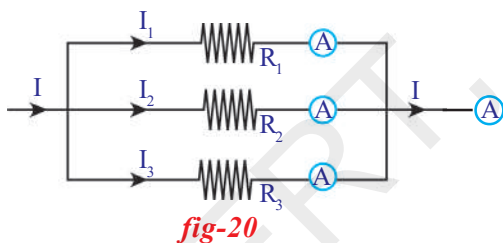
- How much current is drawn from the battery?
- Is it equal to individual currents drawn by the resistors?

Measure the current ( $I$ ) drawn from the battery using the ammeter 1. You will notice that the current drawn from the battery is equal to the sum of individual currents drawn by the bulbs.

Hence we can write

$$I = I_1 + I_2 + I_3 \quad \dots\dots\dots (1)$$

### Equivalent resistance of a parallel connection



The schematic circuit of fig.- 19 is shown in fig.- 20.

According to the Ohm's law,

Current through  $R_1$  is,  $I_1 = \frac{V}{R_1}$

Current through  $R_2$  is,  $I_2 = \frac{V}{R_2}$

Current through  $R_3$ , is,  $I_3 = \frac{V}{R_3}$

Let  $R_{eq}$  be the equivalent resistance of the resistors is parallel. It is shown in fig.- 21.

Then we get;  $I = \frac{V}{R_{eq}}$

Substituting the values  $I, I_1, I_2$  and  $I_3$  in equation (1), we get

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The two resistors  $R_1$  and  $R_2$  are connected in parallel,

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_{eq} = \frac{R_1 R_2}{(R_1 + R_2)}$$

The equivalent resistance of a parallel combination is less than the resistance of each of the resistors.

You can use this result to explain why the resistance of a metal wire is inversely proportional to its area of cross section. Let us imagine a thick wire as a parallel combination of several thin wires. Then the resistance of the combination is less than that of each thin wire. In other words, the resistance of a thick wire is less than that of a thin wire.

**Example 1:** Three resistors  $10 \Omega$ ,  $20 \Omega$ ,  $30 \Omega$ , are connected in

(a) Series (b) Parallel. Find the resultant resistance in the circuit.

Solution: From the given circuit  $R_1 = 10 \Omega$ ,  $R_2 = 20 \Omega$ ,  $R_3 = 30 \Omega$

(a) Resultant resistance in Series connection:  $R = R_1 + R_2 + R_3$

$$R = 10 + 20 + 30 = 60 \Omega$$

(B) Resultant resistance in parallel connection:  $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$$\frac{1}{R} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30} = \frac{11}{60}$$

$$R = 5.5 \Omega$$

**Example 2:** Three resistors  $R_1$ ,  $4 \Omega$ , and  $8 \Omega$ , are connected in series in a circuit. If the resultant resistance in the circuit is  $20 \Omega$  find the value of  $R_1$ .

Solution: Resultant resistance in Series connection:  $R = R_1 + R_2 + R_3$

$$20 = R_1 + 4 + 8$$

$$20 = R_1 + 12$$

$$R_1 = 20 - 12$$

$$R_1 = 8 \Omega$$

**Example 3:** Two resistors  $R_1$  and  $12 \Omega$ , are connected in parallel in a circuit. If the resultant resistance in the circuit is  $3 \Omega$  find the value of  $R_1$ .

Resultant resistance in parallel connection:  $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

$$\frac{1}{3} = \frac{1}{R_1} + \frac{1}{12}$$

$$\frac{1}{R_1} = \frac{1}{3} - \frac{1}{12} = \frac{3}{12} = \frac{1}{4}$$

$$R_1 = 4 \Omega$$

**Example 4:** Observe the given circuit (fig. 22) and calculate the resultant resistance.

Solution: From the given circuit

$R_1 = 4 \Omega$ ,  $R_2 = 12 \Omega$ , are connected in parallel their resultant resistance is

$$R_p = \frac{R_1 R_2}{R_1 + R_2} = \frac{4 \times 12}{4 + 12} = \frac{48}{16} = 3 \Omega$$

$R_p$  is connected to  $R_3$  in series then resultant resistance is

$$R = 3 + 7 = 10 \Omega$$

Though the methods discussed in the previous section for replacing series and parallel combination of resistors by their equivalent resistances are very useful for simplifying many combinations of resistors, they are not sufficient for the analysis of many simple circuits particularly those containing more than one battery.

Let us see.

### Kirchhoff's laws

Two simple rules called Kirchhoff's rules are applicable to any DC circuit containing batteries and resistors connected in any way.

#### Junction Law

See fig.- 19.

We have seen that the current divides at P. The current drawn from the battery is equal to the sum of the currents through the resistors. P is called junction. The junction is a point where three or more conducting wires meet.

At any junction point in a circuit where the current can divide, the sum of the currents into the junction must equal the sum of the currents leaving the junction. This means that there is no accumulation of electric charges at any junction in a circuit.

From fig.- 23, we have

$$I_1 + I_4 + I_6 = I_5 + I_2 + I_3$$

This law is based on the conservation of charge.

#### Loop Law

The algebraic sum of the increases and decreases in potential difference across various components of the circuit in a closed circuit loop must be

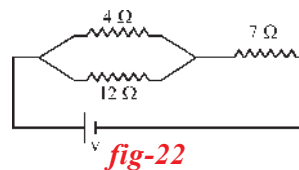


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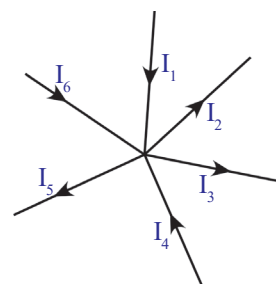


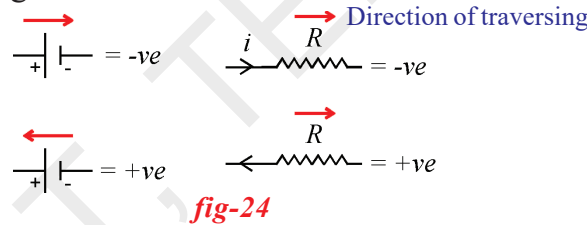
fig-23



zero. This law is based on the conservation of energy.

Let us imagine in a circuit loop the potential difference between the two points at the beginning of the loop has a certain value. As we move around the circuit loop and measure the potential difference across each component in the loop, the potential difference may decrease or increase depending upon the nature of the element like a resistor or a battery. But when we have completely traversed the circuit loop and arrive back at our starting point, the net change in the potential difference must be zero. Thus, the algebraic sum of changes in potential differences is equal to zero.

- How could the sign convention be taken?
  1. emf of the battery is taken as negative when we move from positive terminal to negative terminal across the battery.
  2. It is taken as positive when we move across the battery from negative terminal to positive terminal.
  3. The potential difference across the resistor is taken as negative when we move along the direction of electric current through the resistor.
  4. It is taken as positive when we move against the direction of electric current through the resistor.



**Example 1:** Write the loop equation for the potentials in the given circuit.

*Solution:* In ABCDEA loop,

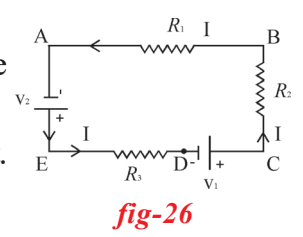
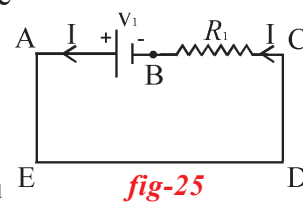
The potential difference at battery is  $-V_1$   
at resistance  $R_1$  the potential difference is  $I R_1$

Net change in the potential difference in the circuit is  $-V_1 + I R_1 = 0$

**Example 2:** Write the loop equation for the potentials in the given circuit.

*Solution:* Let us apply Loop law to the given circuit. From the ABCDEA loop.

At battery  $v_1$  the potential difference is  $-V_1$   
the potential difference at  $v_2$  is  $-V_2$   
Potential difference at resistance  $R_1 = I R_1$



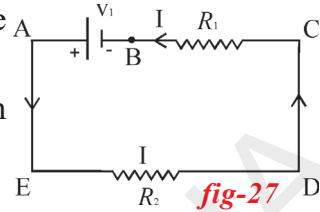
Potential difference at resistance  $R_2 = IR_2$

Potential difference at resistance  $R_3 = IR_3$

Net change in the potential difference in the circuit is

$$IR_1 + IR_2 - V_1 + IR_3 - V_2 = 0$$

**Example 3:** Find the loop equation for the potentials in the given circuit.



*Solution:* Let us apply Loop law to the given circuit.

From Loop ABCDEA

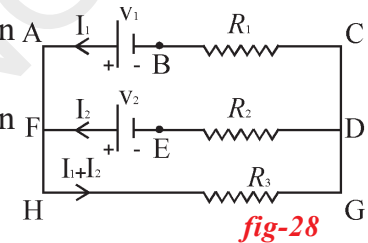
Potential difference at battery is  $-V_1$

Potential difference at resistances are  $IR_1 + IR_2$

Net change in the potential difference in the circuit is

$$-V_1 + IR_1 + IR_2 = 0$$

**Example 4:** Find the loop equation (for all possible loops) for the potentials in the given circuit.



*Solution:* Let us apply Loop law to the given circuit.

**I -** From the ABCDEFA loop

Potential difference at batteries =  $-V_1 + V_2$

Potential difference at resistances =  $+I_1R_1 - I_2R_2$

Net change in the Potential difference in the loop is  $-V_1 + V_2 + I_1R_1 - I_2R_2 = 0$

**II -** From the AFEDCBA loop

Potential difference at batteries =  $-V_2 + V_1$

Potential difference at resistances =  $+I_2R_2 - I_1R_1$

Net change in the Potential difference in the loop is  $-V_2 + V_1 + I_2R_2 - I_1R_1 = 0$

**III -** From the FEDGHF loop

Potential difference at batteries =  $-V_2$

Potential difference at resistances =  $+I_2R_2 + (I_1 + I_2) \times R_3$

Net change in the Potential difference in the loop is  $-V_2 + I_2R_2 + (I_1 + I_2) \times R_3 = 0$

**IV -** From the FHGDEF loop

Potential difference at battery =  $+V_2$

Potential difference at resistances =  $R_3 \times -(I_1 + I_2) - I_2R_2$

Net change in the Potential difference in the loop is  $+V_2 - (I_1 + I_2) \times R_3 - I_2R_2 = 0$

**V -** From the HGCBAH loop

Potential difference at battery =  $+V_1$

Potential difference at resistances =  $-R_3 \times (I_1 + I_2) - I_1R_1$

Net change in the Potential difference in the loop is  $+V_1 - (I_1 + I_2) \times R_3 - I_1R_1 = 0$

VI - From the ABCGHA loop

Potential difference at battery =  $-V_1$

Potential difference at resistances =  $+I_1R_1 + (I_1 + I_2) \times R_3$

Net change in the Potential difference in the loop is  $= -V_1 + I_1R_1 + (I_1 + I_2) \times R_3 = 0$

**Example 5 :** Find the loop equation (all possible loops) for the potentials in the given circuit.

*Solution:* Shown in

For the loop ACDBA,

$$-V_2 + I_2R_2 - I_1R_1 + V_1 = 0$$

For the loop EFDCE

$$-(I_1 + I_2)R_3 - I_2R_2 + V_2 = 0$$

For the loop EFBAE

$$-(I_1 + I_2)R_3 - I_1R_1 + V_1 = 0$$

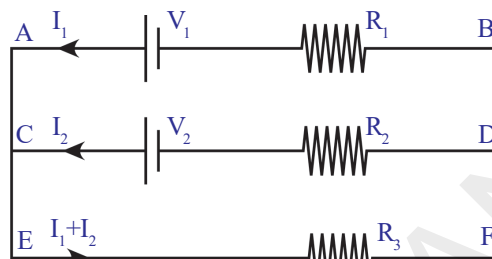


fig-29

**Example 6:** Find the electric current (fig 30) drawn from the battery of emf 12V.

*Solution:* Do proper current distribution using junction law.

Using loop law in loop DAFED

$$-3I_1 + 12 - 4I = 0$$

$$4I + 3I_1 = 12 \dots (a)$$

For loop DABCD

$$-3I_1 + 12 - 5 + 2(I - I_1) = 0$$

$$2I - 5I_1 = -7 \dots (b)$$

Solving the equation (a) & (b)  $I_1 = 2A$

Current drawn from battery of 12V is  $I_1 = 2A$

- You might have heard the sentences like “this month we have consumed 100 units of current”. What does ‘unit’ mean?

- A bulb is marked 60W and 220V. What do these values indicate?

Let us see.

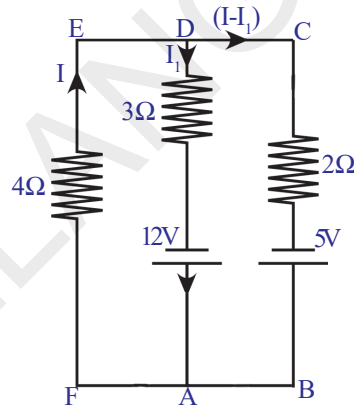


fig-30

## Electric power

The electric appliances that we use in our daily life like heater, cooker, fan, and refrigerator etc. consume electric energy. Let us consider a conductor of resistance ‘R’ through which an electric current ‘I’ passes. We know that when current passes through conductor, heat energy is generated.

Consider that a charge Q Coulomb passes through a point A, moves to point B

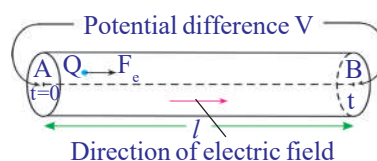


fig-31

in the time interval 't' seconds as shown in fig.- 31. Let V be the potential difference between the points A and B. The work done by electric field in time 't' is given by

$$W = QV \quad \dots\dots\dots(1)$$

This work is equal to the energy lost by the charge while passing through the conductor.

- What is the energy lost by the charge in 1 sec?

It is equal to  $\frac{W}{t}$ .

From equation (1), we get

$$\frac{W}{t} = \frac{QV}{t} \quad \dots\dots\dots(2)$$

In above equation  $\frac{Q}{t}$  represents the current (I) flowing through the conductor and  $\frac{W}{t}$  represents the work done per second.

In lower classes you had studied that power is nothing but the rate of doing work. Hence,  $\frac{W}{t}$  represents electric power (P).

$$\text{Electric power } P = VI \quad \dots\dots\dots(3)$$

This equation can be used to calculate power consumption by any electric device that is connected in a circuit.

According to the ohm's law,

$$V = IR$$

We can write equation (3) as

$$P = I^2 R = \frac{V^2}{R}$$

The equation  $P = VI$  can also be used to know the power that can be extracted from a battery or any source. In such case we modify the equation  $P = VI$  as  $P = \epsilon I$ .

Where  $\epsilon$  is the emf of the battery.

Let us consider an example to understand power consumption.

A bulb is marked 60W and 120V. This means that if this bulb is connected to 120V source, it will able to convert 60J of electrical energy into heat or light in one second.

Thus, the bulbs marked as 60W and 120V will offer a resistance of 240  $\Omega$  to the flow current through it in normal condition.

From the marking of bulb we can measure the resistance of the bulb.

$$\text{From the relation } P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P}$$

Substituting the values V and P in above equation, we get

$$R = \frac{120 \times 120}{60} = 240 \Omega$$

If this bulb is connected to the 12V a battery, the consumption by the bulb is given by

$$P = \frac{V^2}{R} = \frac{12 \times 12}{240} = \frac{3}{5} = 0.6 \text{ W}$$

Since watt is a small unit of power, a bigger unit Kilowatt is generally used to express power consumption.

$$1 \text{ KW} = 1000 \text{ W} = 1000 \text{ J/S}$$

You might have seen the current bill that comes to your home every month. In that bill, consumption of electricity is marked in units. What does the unit represent?

The unit of electric power consumption is equal to 1 KWH (one Kilo Watt Hour).

$$\begin{aligned} 1 \text{ KWH} &= (1000 \text{ J/S}) (60 \times 60 \text{ S}) \\ &= 3600 \times 1000 \text{ J} \\ &= 3.6 \times 10^6 \text{ J} \end{aligned}$$

- What do you mean by overload?
- Why does it cause damage to electric appliances?

We frequently hear news about overload of current and damages caused by this overload.

Electricity enters our homes through two wires called lines. These line wires have low resistance and the potential difference between the wires is usually about 240V. These two line wires run throughout the household circuit, to which we connect various appliances such as fan, TV, refrigerator etc.

All the electric devices of our home are connected at different points between these two wires. This means all the electric appliances are in parallel connection. Hence, potential drop across each device is 240V. If we know the value of resistance of the electric device, we can calculate the current passing through it using the equation  $I = V/R$ . For example, the current passing through a bulb with resistance  $240 \Omega$  is 1 A.

Based on the resistance of each electric device, it draws some current from the supply. Total current drawn from the mains is equal to the sum of the currents passing through each device (Junction law).

If we add more devices to the household circuit the current drawn from the mains also increases.

- What happens when this current increases greatly?

To answer this, observe the values noted on digital meters fixed at your home. You will notice the following values on the meter.

Potential difference: 240 V

Current: 5 – 20A

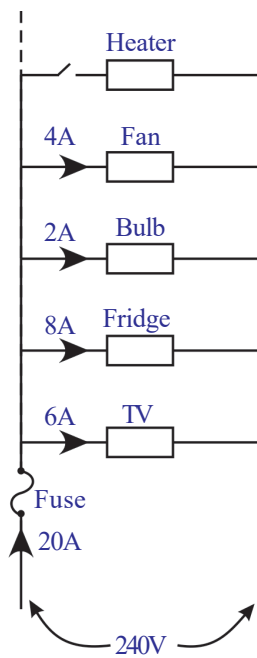


fig-32

This means the line wires that are entering the meter have a potential difference of 240V. The minimum and maximum limit of current that can be drawn from the mains is 5 – 20A. Thus, the maximum current that we can draw from the mains is 20A. When the current drawn from the mains is more than 20A. Overheating occurs and may cause a fire. This is called over loading. See fig.- 32. If we switch on devices, such as heater shown in fig.- 32, the current drawn from the mains exceeds the max limit 20A.

- How can we prevent damage due to overloading?

To prevent damages due to overloading we connect an electric fuse to the household circuit as shown in fig.- 32. In this arrangement, the entire current from the mains must pass through the fuse. The fuse consists of a thin wire of low melting point. When the current in the fuse exceeds 20A, the wire will heat up and melt. The circuit then becomes open and prevents the flow of current into the household circuit. So all the electric devices are saved from damage that could be caused by overload.

Thus we can save the house holding wiring and devices by using fuses.

**Note:** The value of overload current varies from the household currents to factories.



### Think and discuss

- What do you mean by short circuit?
- Why does a short circuit damage electric wiring and devices connected to it?



### Key words

*Charge, Potential difference, Electric current, Multi-meter, Ohm's law, Resistance, Resistivity, Kirchhoff's laws, Electric power, Electric energy.*



## What we have learnt

- Electric current is expressed as the amount of charge flowing through a particular cross section of area in unit time.
- A multi-meter is an electronic measuring instrument that combines several measuring functions (electric potential difference, electric current and electric resistance) in one unit.
- **Ohms law:** The current through a conductor element is proportional to the potential difference applied between its ends, provided the temperature remains constant. Mathematically  $V=IR$ .
- Ohm's law is valid for metal conductors at constant temperature. It is not applicable for gaseous conductors and semiconductors.
- Resistance is the opposition that a substance offers to the motion of electrons.
- Resistance of a wire depends on the material of the wire, its length and its area of cross section  $R \propto l/A$ .
- The resistivity of a material is the resistance per unit length of a unit cross section of the material.
- Two or more resistors are said to be connected in series if the same current flows through them.
- **The junction law:** At any junction point in a circuit where the current can divide, the sum of the currents into the junction must equal the sum of the currents leaving the junction.
- **The loop law:** The algebraic sum of the increases and decreases in potential difference across various components of a closed circuit loop must be zero.
- Electric power is the product of potential difference and the current. SI unit of power is watt (W).
- Electrical energy is the product of power and time. Units of electrical energy W-s and KWH.



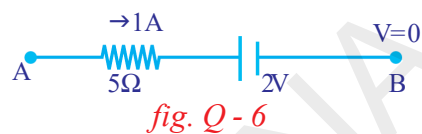
## Improve your learning

### Reflections on concepts

1. Explain how electron flow causes electric current with Lorentz – Drude theory of electrons. (AS<sub>1</sub>)
2. Write the difference between potential difference and emf. (AS<sub>1</sub>)



- How can you verify that the resistance of a conductor is temperature dependent? (AS<sub>1</sub>)
- Explain how electric shock takes place. (AS<sub>1</sub>)
- Draw a circuit diagram for a circuit in which two resistors A and B are connected in series with a battery and a voltmeter is connected to measure the potential difference across the resistor A. (AS<sub>5</sub>)
- In the figure Q-6 the potential at A is \_\_\_\_\_ when the potential at B is zero. (AS<sub>7</sub>)



### Application of concepts

- Explain overloading of household circuit. (AS<sub>1</sub>)
- Why do we use fuses in household circuits? (AS<sub>1</sub>)
- Two bulbs have ratings 100 W, 220V and 60 W, 220 V. Which one has the greater resistance? (AS<sub>1</sub>)
- Why do we consider tungsten as a suitable material for making the filament of a bulb? (AS<sub>2</sub>)
- Are the head lights of a car connected in series or parallel? Why? (AS<sub>2</sub>)
- Why should we connect electric appliances in parallel in a household circuit? What happens if they are connected in series? (AS<sub>2</sub>)
- If the resistance of your body is 100000Ω. What would be the current that flows in your body when you touch the terminals of a 12V battery? (AS<sub>7</sub>)

### Higher Order Thinking Questions

- Imagine that you have three resistors of 30Ω each. How many resultant resistances can be obtained by connecting these three in different ways? Draw the relevant diagrams.
- A house has 3 tube lights, two fans and a Television. Each tube light draws 40W. The fan draws 80W and the Television draws 60W. On the average, all the tube lights are kept on for five hours, two fans for 12 hours and the television for five hours every day. Find the cost of electric energy used in 30 days at the rate of Rs. 3.00 per Kwh. (AS<sub>7</sub>)





7. The current in the wire depends [     ]
- a) only on the potential difference applied     b) only on the resistance of the wire
- c) on both of them     d) none of them

### Suggested Experiments

1. State Ohm's law. Suggest an experiment to verify it and explain the procedure. (AS<sub>3</sub>)
2. How do you verify that resistance of a conductor is proportional to the length of the conductor for constant cross section area and temperature? (AS<sub>3</sub>)

### Suggested Projects

- 1.a. Take a battery and measure the potential difference. Make a circuit and measure the potential difference when the battery is connected in the circuit. Is there any difference in potential difference of battery? (AS<sub>4</sub>)
- b. Measure the resistance of a bulb (filament) in open circuit with a multi-meter. Make a circuit with elements such as bulb, battery of 12V and key in series. Close the key. Then again measure the resistance of the same bulb (filament) for every 30 seconds. Record the Observations in a proper table. What can you conclude from the above results? (AS<sub>4</sub>)
2. Calculate the resistance of various bulbs that you use at your home and find which one is having higher / lower resistance value. Write the report on your observations.
3. Collect the information and prepare a report on power consumption in your home / school.

# Annexure

## Can we apply Newton law's to the motion of electrons?

**Note:** In this explanation, the random motion of electrons is neglected.

Let us consider a conductor of length  $l$  and cross sectional area  $A$ . Let  $n$  be the density of electrons of a conductor.

The current passing through the conductor when the ends of the conductor is maintained at a constant potential difference  $V$  is given by

$$I = nAev_d \quad \dots\dots\dots (a)$$

Where  $e$  is the charge of electron and  $v_d$  is the drift velocity of electrons.

Work done by the source to move electron between the ends (along the conductor) is given by,

$$W = Ve \quad \dots\dots\dots (b)$$

We know that the work done by the electric force,

$$W = Fl \quad \dots\dots\dots (c)$$

Where  $F$  is the force applied by the electric field.

From equations (b) and (c), We get

$$Fl = Ve \quad \Leftrightarrow \quad F = Ve/l$$

From Newton's second law, we know that  $F = ma$  is applicable to any particle. Hence we have,

$$ma = Ve/l \quad \Leftrightarrow \quad a = Ve/lm \quad \dots\dots\dots (d)$$

Assuming that the initial velocity ( $u$ ) of electron is zero. Let  $v$  velocity acquired by the electron in a time interval  $\tau$  (interval between successive collisions). Then  $u = 0$  and  $t = \tau$

From equation  $v = u + at$

$$v = a\tau = Ve\tau/lm \quad (\text{from equation d})$$

Due to collisions with lattice ions, the motion of electrons is restricted. Hence the average velocity of electron in time  $\tau$  becomes its drift velocity.

$$\text{Average velocity of electron } v_d = (v+u)/2 = v/2$$

Substituting the value of  $v$  in above equation, we get

Average velocity = Drift velocity,  $v_d = V e \tau / 2 m$

Substituting the value of  $v_d$  in equation (a) we get,

$$I = n A e (V e \tau / 2 m)$$

$$I = V (n e^2 \tau / 2 m) (A / l)$$

$$I (2 m / n e^2 \tau) (l / A) = V \quad \dots\dots\dots(e)$$

In the above equation, mass of the electron ( $m$ ) and charge of the electron ( $e$ ) are constants because these values are characteristics of the electron.

The electron density ( $n$ ) of a metal conductor depends on its nature so it is also constant for a particular conductor.

For a given conductor, the length ( $l$ ) and cross section area ( $A$ ) are also constants. The value of  $\tau$  depends on temperature of the conductor. When the temperature increases the random motion of electrons increases hence the value of  $\tau$  decreases.

For a constant temperature of a conductor the value of  $\tau$  becomes constant.

Hence  $(2 m / n e^2 \tau) (l / A)$  becomes a constant for a particular conductor at constant temperature. Let this value be  $R$  (called resistance of a conductor). Then we get

$$I R = V \quad (\text{from equation e}) \quad \dots\dots\dots(f)$$

This is what we call Ohm's law.

$$\text{Where } R = (2 m / n e^2 \tau) (l / A) \quad \dots\dots\dots(g)$$

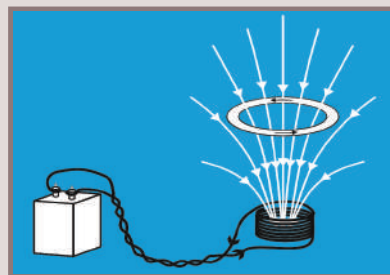
In the above equation  $2 m / n e^2 \tau$  is the characteristic value of a conductor. The value of resistance  $R$  is different for different geometrical values for a particular conductor (material). Hence  $2 m / n e^2 \tau$  is taken as a constant independent of geometrical values. Let it be  $\rho$ . It is called specific resistance.

$$\rho = 2 m / n e^2 \tau$$

From equation (g) we get

$$R = \rho l / A \quad \dots\dots\dots(h)$$

Note: Drift velocity and Drift speed are synonym



# Electromagnetism

In the previous chapter on ‘Electricity’ you have learnt about the heating effects of electric current. We use many electric appliances in our daily life such as electric motor, electric generators, electric calling bells, electric cranes etc.,

- How do they work?
- How do electromagnets work?
- Is there any relation between electricity and magnetism?
- Can we produce magnetism from electricity?

In this chapter we will study electromagnetic effects. We also study electric motors which involve magnetic effects of electric current and electric generator which involves electric effects of moving magnets.



**Hans Christian Oersted (1777 - 1851)** was one of the leading scientists of the 19<sup>th</sup> century, played a crucial role in understanding *electromagnetism*. He gave lectures which were quite popular among the public and also learnt a lot during the tours. During one such lecture in April 1820, Oersted carried out an experiment that was never performed before. He placed a compass needle underneath a wire and then turned on electric current. The needle of compass showed deflection.

Oersted recognized the significance of what he had just done. Earlier, it was believed that electricity and magnetism were two different unconnected sciences. Oersted had demonstrated that they were interconnected. Through this observation he showed that electricity and magnetism were related phenomena. Some scientists, influenced by this experiment, continued to work in the modern field of

“electromagnetism”. Their research resulted in several new scientific theories and various vital inventions like the dynamo and the electric motor, with this a new technology prospered, leading to inventions such as radio, television and fiber optics.

The unit of magnetic field strength is named Oersted in his honour.

Oersted was made a foreign member of the Royal Swedish Academy of Sciences in 1822.

## Activity 1

### Oersted experiment

Take a thermocole sheet and fix two thin wooden sticks of height 1 cm which have small slit at the top of their ends. Arrange a copper wire of 24 gauge so that it passes through these slits and make a circuit. The circuit consists of a 3 (or 9) volt battery, key and copper wire which are connected in series as shown in figure 1. Now, keep a magnetic compass below the wire. Bring a bar magnet close to the compass.

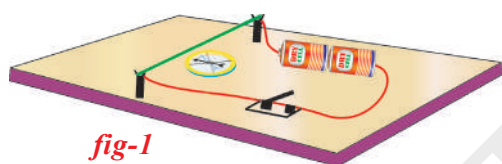


fig-1

- Does the needle get deflected by the bar magnet?
- Why does the needle get deflected by the magnet?

Take the bar magnet far away from the circuit and switch on the circuit. Look for changes in the position of the needle.

- What do you notice?
- Is there any change in the position of the compass needle?
- Which force is responsible for the deflection of the compass needle?
- Does the current-carrying wire apply a force on the needle?
- What do we call this force? (Recall the idea of field forces in class 8, chapter “Force”).

In order to understand the reasons for the deflection of the compass needle with no bar magnet near it we need to understand the idea of ‘magnetic field’ and the influence of electric field on magnetic field.

Let us learn about it.

### Magnetic Field

We use the term field when a force gets applied on an object by another object without there being any physical contact between them. You have observed this already in activity 1. Let us call this field which is responsible for deflection of the compass needle as ‘magnetic field’.

- How was this field produced?
- Can we observe the field of a bar magnet?

Let us try.

## Activity 2

Take a sheet of white paper and place it on the horizontal table. Place a bar magnet in the middle of the sheet. Place a magnetic compass near the magnet. It settles to a certain direction. Use a pencil and put dots on the sheet on either side of the needle. Remove the compass. Draw a small line segment connecting the two dots. Draw an arrow on it from South Pole of the needle to North Pole of the needle. Repeat the same by placing the compass needle at various positions on the paper. The compass needle settles in different directions at different positions.

- Why does this happen?

Remove the bar magnet and place the magnetic compass on the paper. It comes to rest along the north-south direction. Now place the bar magnet in its previous place.

- Is there any change in the direction of the needle of the magnetic compass? Why?

The needle of the magnetic compass is affected by the bar magnet without any physical contact. A force causes the needle to deflect and makes it to come to rest in a certain direction.

- What is the nature of force that acts on the needle?

The force which acts on the needle from a distance is due to the magnetic field of the bar magnet.

In activity 2, you have already seen that the orientation of needle is different at different places on paper. This gives us an idea that the magnetic field has direction and it varies from one point to another.

When you changes the place of the compass near the bar magnet you can observe that its orientation changes from point to point. Now take the needle to places far away on the sheet and observe the orientation of the compass needle in each case.

- What do you observe?

The compass needle shows almost the same direction along north and south at places far from the magnet.

- What does it mean?

From these observations we conclude that the strength of the field varies with distance from the bar magnet. Now hold the compass a little above the table and at the top of the bar magnet. You can observe that field exists in all directions around the bar magnet. Hence we can say that the

magnetic field is three dimensional i.e., magnetic field surrounds its source such as bar magnet. From the above discussion we can generalize that:

A magnetic field exists in the region surrounding a bar magnet and is characterized by strength and direction.

### Lines of magnetic field

- How can we find the strength of the field and direction of the field?

You know that the direction of the field can be determined by using a compass. Let us find out how to determine the strength of the field.

#### Activity 3

Place a white sheet of paper on a horizontal table. Place a compass in the middle of it. Put two dots on either side of the compass needle. Take it out. Draw a line connecting the dots which shows the North and South of the earth. Now place the bar magnet on the line drawn in such a way that its north pole points towards geographic north. Now place the compass at the north pole of the bar magnet. Put a dot at the north pole of the compass needle. Now remove the compass and place it at the dot. It will point in other direction. Again put a dot at the north pole of the compass needle. Repeat the process till you reach the south pole of the bar magnet. Connect the dots from 'N' of the bar magnet to 'S' of the bar magnet. You will get a curved line. Now select another point from the north pole of the bar magnet.

Repeat the process for many points taken near the north pole. You will get different curves as shown in fig.-2.

- What are these curves?

Technically these curves are called “magnetic field lines”. Field lines are imaginary lines. These lines help us to understand the nature of the field. So these curved lines represent the field lines. If you place a compass at any point on the line, the needle comes to rest

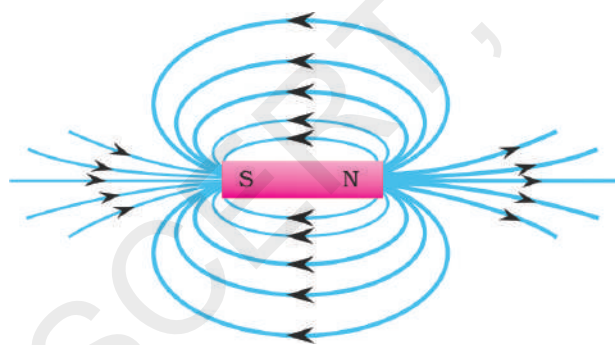


fig-2: Magnetic field lines

along the tangent to the line. So we conclude that the tangent drawn to the field line at a point gives the direction of the field.

- Are these field lines closed or open loops?

The field lines appear to be closed loops, but you can't conclude that lines are closed or open loops by looking at the picture of field lines because we do not know about the alignment of lines that are passing



through the bar magnet. We will come to know about this point later in this chapter.

Observe the spacing between lines. In some places the field lines are crowded (near the poles of a bar magnet) and in some places the field lines are spread apart (at long distances from the bar magnet). From this picture we can conclude that the field is strong when lines are crowded and field is weak when lines are spaced apart.

Thus, the field drawn is non uniform because the strength and direction both change from point to point.

We may define the nature of the field with its characteristics such as its strength and direction. The field is said to be non uniform when any one of the characteristics of field i.e., strength or direction changes from point to point. Similarly the field is said to be uniform if both strength and direction are constant throughout the field. Let us define the strength of a uniform magnetic field.

- Can we give certain values to magnitude of the field at every point in the magnetic field?

### Magnetic flux - Magnetic flux density

Consider a uniform magnetic field in space. Imagine a plane of certain area 'A' placed perpendicular to the field at a certain point in the magnetic field as shown in figure 3(a). You notice that a few field lines pass through this plane. This number gives an estimation of strength of the field at that point.

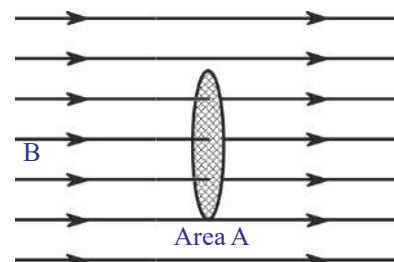


fig-3(a)

The number of lines passing through the plane of area 'A' perpendicular to the field is called magnetic flux. It is denoted by ' $\Phi$ '.

Magnetic flux represents the number of lines passing through the imagined plane in the field. Of course, flux depends on the orientation of the plane in the field. But here we are concerned only with the perpendicular case. The S.I unit of magnetic flux is Weber. Now strength of the field is easily defined using the idea of flux. If the imagined plane is perpendicular to the field and has unit area, then the flux through this plane of unit area gives the strength of the field. This strength of the field is technically called magnetic flux density (**B**). So, magnetic flux density is defined as the magnetic flux passing through unit area taken perpendicular to the field. **B** is also known as magnetic field induction.

Let the flux through the area 'A' be  $\Phi$ .

- What is the flux through unit area perpendicular to the field?

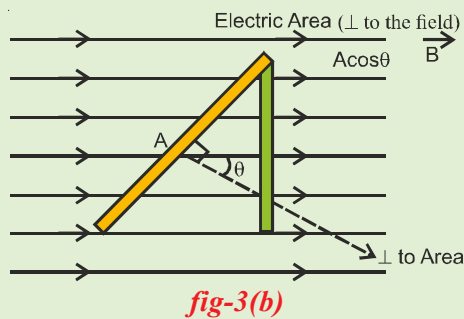
It is equal to  $\frac{\Phi}{A}$ . The ratio of magnetic flux passing through a plane perpendicular to the field and the area of the plane is called the magnetic flux density.

So magnetic flux density = magnetic flux/ area.

$$B = \frac{\Phi}{A} \Rightarrow \Phi = BA$$

Units of magnetic flux density is Weber/(meter)<sup>2</sup>. It is also called Tesla.

### Generalize the formula of flux for any orientation of the plane taken in the field.



Let 'θ' be the angle between magnetic field (B) and normal to the plane with area (A) as shown in figure 3(b). The effective area of the plane perpendicular to the field is  $A \cos \theta$ . Then magnetic flux density is given by,

$$B = \frac{\text{magnetic flux}}{\text{effective area}}$$

(this formula is used when plane makes an angle with the field).

$$\text{Then } B = \frac{\Phi}{A \cos \theta}$$

The flux through the plane, is given by

$$\Phi = BA \cos \theta.$$

- What is the flux through the plane taken parallel to the field?
- What is the use of introducing the ideas of magnetic flux and magnetic flux density?

Later in this chapter, you will see how these ideas are used.

- Are there any sources of magnetic field other than magnets?
- Do you know how old electric calling bells work?

Let us see

### Magnetic field due to currents

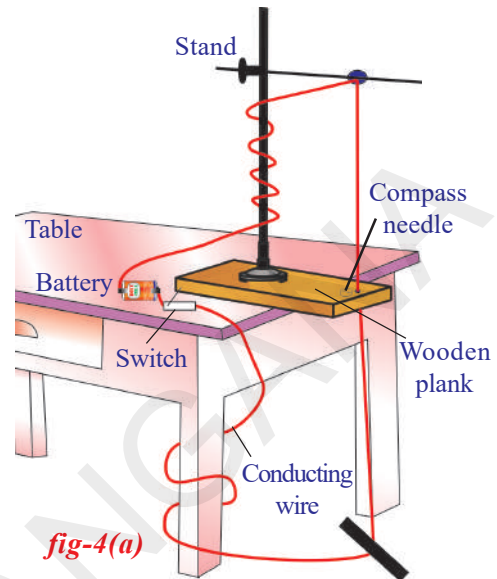
In activity 1 we observed that the compass needle is deflected when current flows through the circuit. This observation helps us to conclude that, "Current carrying wire produces magnetic field."

Let us discuss about the magnetic fields produced by a current carrying wire.

## (i) Magnetic field due to straight wire carrying current

### Activity 4

Take a wooden plank and make a hole as shown in figure 4(a). Place this plank on the table. Now place a retort stand on the plank as shown in figure 4(a). Pass 24 gauge copper wire through hole of the plank and rubber knob of the retort stand in such a way that the wire be arranged in a vertical position and not touch the stand. Connect the two ends of the wire to a battery via switch. Place 6 to 10 compass needles in a circular path around the hole so that its centre coincides with the hole. Use 3 (or 9) volt battery in the circuit. Switch on. Current flows through the wire.



- How do the directions of the compass needles change?

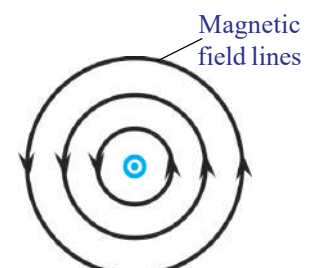
You may notice that they are directed as tangents to the circle.

- What is the shape of the magnetic field line around wire?

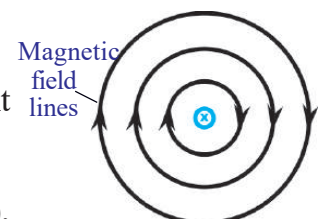
It must be a circular line. So we conclude that magnetic field lines are closed lines. The magnetic field lines due to straight wire carrying the current is shown in figures 4(b) and 4(c). This can be verified by sprinkling iron filings around the wire when current flows in the wire.

- What is the direction of magnetic field induction at any point on the field line?

If the current flow is vertically upwards (out of the page), the field lines are in anticlockwise direction, as shown in figure 4(b). If current flows into the page, in downward direction, the field lines are in clockwise direction as shown in figure 4(c). How do we determine the direction of field lines? It can be easily determined with **right hand thumb rule**. If you grab the current carrying wire with your right hand in such way that thumb is in the direction of current, then the curled fingers show the direction of the magnetic field as shown in figure 4(d).



⊙ Current out of the page  
fig-4(b)



⊗ Current into the page  
fig-4(c)

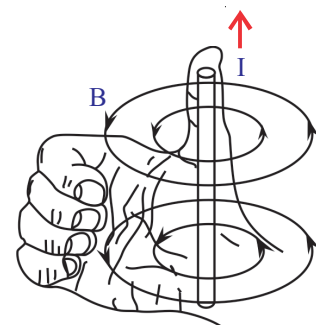
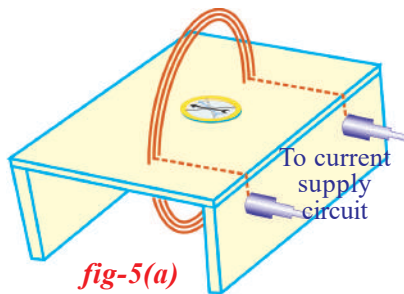


fig-4(d)

## (ii) Magnetic field due to circular coil

### Activity 5



Take a thin wooden plank covered with white paper and make two holes on its surface as shown in figure 5(a). Pass insulated copper wire (24 gauge) through the holes and wind the wire 4 to 5 times through holes such that it looks like a coil (figure 5(a)). The ends of the wire are connected to terminals of the battery through a switch. Now switch on the circuit. Place a

compass needle on the plank at the centre of the coil. Put dots on either side of the compass. Again place compass at one of the dots, put other dot further. Do the same till you reach the edge of the plank. Now repeat this for the other side of the coil from the centre. Then draw a line joining the dots, you will get a field line of the circular coil. Do the same for the other points taken in between the holes. Draw corresponding lines. You will get field lines of the circular coil.

- Can you tell the direction of the magnetic field of the coil?

This could be answered from the orientation of the compass needle. You can observe this when the compass needle is kept at the centre of the coil. The direction in which the compass needle comes to rest indicates the direction of the field due to the coil. Thus the direction of the field is perpendicular to the plane of the coil.

- Why does the compass needle point in the direction of field?

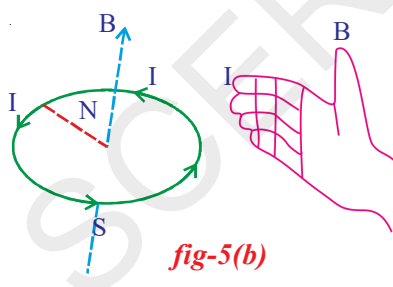
Place the compass in front of one of the faces of the coil and observe the orientation of the compass needle. Note the pole of the needle that

faces the coil. We know that south pole is attracted to the north pole. The needle is oriented in such a way that its south pole points towards the north pole of the coil. So we can say that the direction of magnetic field, due to coil, points towards you when the current in the coil is in anticlockwise direction. Verify this in your experiment (do not touch the wires of the coil). When the current in the coil is in clock-wise direction, the

direction of magnetic field due to the coil points away from you. The direction of the field due to coil is determined by using right hand rule, which states that,

“When you curl your right hand fingers in the direction of current, thumb gives the direction of magnetic field.”

Observe the direction of magnetic field in figure 5(b).



### (iii) Magnetic field due to solenoid

#### Activity 6

Take a wooden plank covered with white paper. Make equidistant holes on its surface as shown in figure 6(a). Pass copper wire through the holes as shown in figure 6(a). This forms a coil. Join the ends of the coil to a battery through a switch. Switch on the circuit. Current passes through the coil. Now sprinkle iron filings on the surface of the plank around the coil. Give a small jerk to it. An orderly pattern of iron filings is seen on the paper.

- How do they adjust in such an orderly pattern?

This long coil is called solenoid. A solenoid is a long wire wound in a close packed helix. The field of solenoid is shown in the figure 6(b). The magnetic field lines set up by solenoid resemble those of a bar magnet indicating that a solenoid behaves like a bar magnet. The direction of the field due to solenoid is also determined by using right hand rule. One end of the solenoid behaves like a north pole and other behaves like a south pole. The field lines outside the solenoid are continuous with those inside. Outside the solenoid the direction of the field lines is from north to south while inside the direction is from south to north. Thus the magnetic field lines are closed loops. This is so for the bar magnet too!

We have seen that current carrying wires produce magnetic field. So, electric charges in motion produce magnetic fields.

- What happens when a current carrying wire is kept in a magnetic field?  
Let us see.

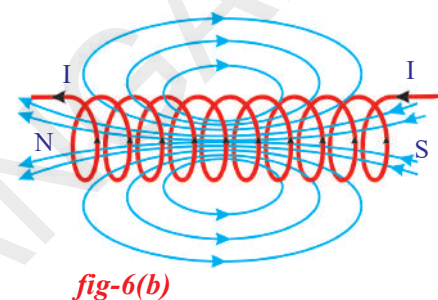
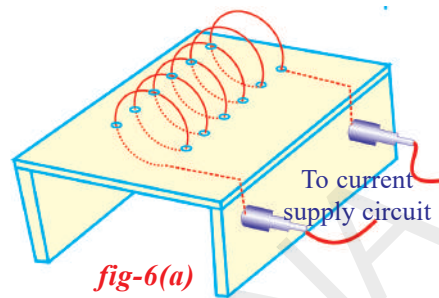
### Magnetic Force On Moving Charge And Current Carrying Wire

#### Activity 7

Take a bar magnet and bring it near the TV screen (The old CRT type TV). What do you observe?

You can observe that the picture on the screen is distorted.

- Why does the picture get distorted?
- Is the motion of electrons reaching the screen affected by the magnetic field of the bar magnet?



Move the bar magnet away from the screen. Now you will get a clear picture. Repeat this to confirm that the motion of electrons is affected by the field produced by the bar magnet. This must be due to the fact that the magnetic field exerts a force on the moving charges. This force is called magnetic force.

- Can we calculate the force experienced by a charge moving in a magnetic field?

X indicates the direction of B and it is into the page

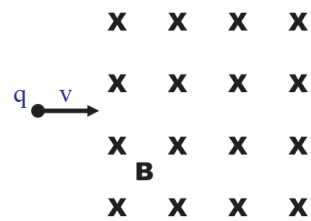


fig-7

Let a charge 'q' move with a velocity 'v' perpendicular to the magnetic field 'B' as shown in figure 7. The value of magnetic force on the moving charge can be found experimentally and it is given by,

$$F = q v B$$

Magnetic force on the charge is the product of three quantities charge, speed and magnetic flux density. The equation for magnetic force acting on a charge 'q' is  $F = q v B$  and holds well only when the direction of velocity of charged particle 'v' is perpendicular to the direction of the magnetic field 'B'.

Generalize the equation for magnetic force on charge when there is an angle 'θ' between the directions of field **B** and velocity **v**.

It is experimentally proved that when there is an angle between direction of field and velocity, the magnetic force experienced by the charge is given by,

$$F = q v B \sin\theta.$$

When charge moves parallel to the magnetic field (along the magnetic field or against the field) the value of θ becomes zero. In the above equations θ is 0° so that  $\sin\theta = 0$ .

Thus the charge experiences no force when it is moving parallel to the magnetic field (along field direction or against field direction).

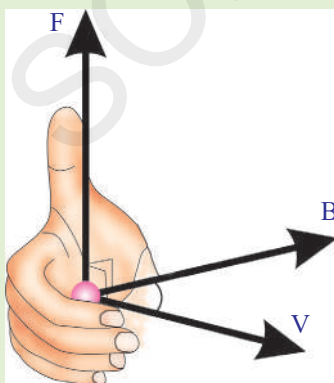


fig-8(a)

We have an easy method to find out the direction of magnetic force acting on a charge moving in a magnetic field. Keep your right hand fingers along the direction of velocity of moving charge and next curl your fingers towards the direction of magnetic field then the thumb gives the direction of magnetic force as shown in figure 8(a). This rule is applied for any case of angle between directions of velocity and field. The direction of magnetic force is always perpendicular to the direction of both velocity and magnetic field.

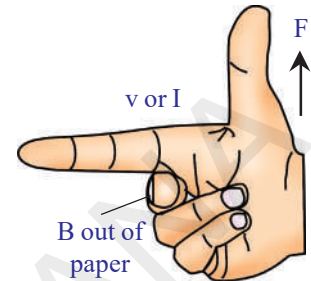
Generally right hand rule is used when velocity and field are perpendicular to each other. This law states that, “If the fore-finger points towards the direction of velocity of charge or current, middle finger points to the direction of field (B) then thumb gives direction of force when the three fingers are stretched in such a way that they are perpendicular to each other as shown in figure 8(b).”

This rule is applicable to positive charge.

- What is the direction of force acting on a negative charge moving in a field?

First find the direction of force acting on a positive charge. Next reverse its direction. This new direction is the direction of force acting on the negative charge.

Let us see an example of force acting on a charged particle.



**fig-8(b): Right hand rule for positive charge**

### Example 1

A charged particle ‘q’ is moving with a speed ‘v’ perpendicular to the magnetic field of induction B.

Find the radius of the path and time period of the particle.

**Solution:** Let us assume that the field is directed into the page as shown in figure E-1. Then the force experienced by the particle is  $F = q v B$ . We know that this force is always directed perpendicular to velocity. Hence the particle moves along a circular path and the magnetic force on a charged particle acts like a centripetal force.

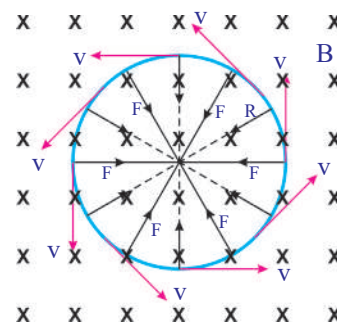
Let r be the radius of the circular path.

We know that centripetal force =  $\frac{mv^2}{r}$

$$q v B = \frac{mv^2}{r}$$

Solving this equation, we get;  $r = \frac{mv}{Bq}$

Time period of the particle;  $T = \frac{2\pi r}{v}$



**fig-E-1**

Substituting r in above equation, we get  $T = \frac{2\pi m}{Bq}$

- What happens when a current carrying wire is placed in a magnetic field?

Electric current is charges in motion. We know that each charge experiences a magnetic force. Thus the current carrying wire (constituting

collection of charges in motion) experiences magnetic force when it is kept in a magnetic field.

- Can you determine the magnetic force on a current carrying wire which is placed along a magnetic field?

We know that each charge experiences no magnetic force because they are moving parallel to the direction of field along the field. So the force acting on wire is zero when it is kept along a magnetic field.

Let us find the magnetic force on a straight wire carrying current which is kept perpendicular to a uniform magnetic field 'B'. This 'B' is directed into the page. It is represented by 'x' as shown in the figure 9. Let the field be confined to the length L. So only the part of the wire of the length 'L' is inside the magnetic field. Remaining wire is outside the magnetic field. We know that the electric current means charges in motion hence they move with a certain velocity called drift velocity 'v'.

The magnetic force on a single charge is given by,

$$F_0 = q v B$$

Let total charge inside the magnetic field be Q. So magnetic force on the current carrying wire is given by

$$F = Q v B \quad \dots\dots\dots(1)$$

The time taken by the charge (Q) to cross the field be

$$t = \frac{L}{v} \Rightarrow v = \frac{L}{t} \quad \dots\dots\dots(2)$$

substituting this in equation 1, we get,

$$F = \frac{QLB}{t} \Rightarrow F = \frac{Q}{t} LB \quad \dots\dots\dots(3)$$

We know that  $\frac{Q}{t}$  is equal to the electric current in the wire,

$$I = \frac{Q}{t}$$

Substituting 'I' in the equation 3, we get

$$F = ILB \quad \dots\dots\dots(4)$$

**Note:** This equation holds well only when direction of electric current is perpendicular to magnetic field.

In fig.-9, you can observe the bending in the wire due to the force applied on it.

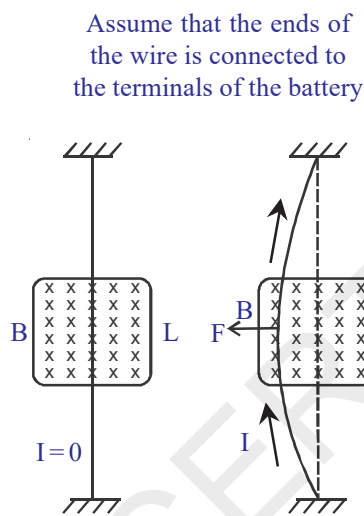


fig-9



- What is the force on the wire if its length makes an angle 'θ' with the magnetic field?

Let 'θ' be the angle between direction of current and magnetic field, then the force acting on the current carrying wire is given by

$$F = ILB \sin\theta \text{ (at any angle) } \dots\dots\dots(5)$$

- How could you find its direction?

You can use right hand rule to find out the direction of force on the current carrying wire.

Let us see the result of force applied on a current carrying wire by an experiment.

### Activity 8

Take a wooden plank. Fix two long wooden sticks on it. These wooden sticks are split at their top ends.

A copper wire is passed through these splits and the ends of the wire are connected to battery of 3 volt, through a switch. Close the switch to make the circuit. Current passes through the wire. Now bring a horseshoe magnet near the copper wire as shown in figure 10.

- What happens to the wire?
- In which way does it deflect?

Use the right thumb rule to find the direction of force.

- Is the direction of deflection observed experimentally same as that of the theoretically expected one?

Change polarities of the horse shoe magnet. Again observe the deflection. Repeat this by changing the direction of current in the circuit.

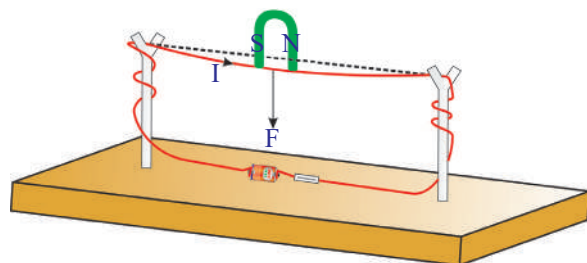


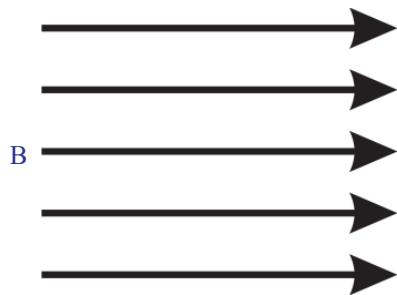
fig-10

- Does the right hand rule give the explanation for the direction of magnetic force exerted by magnetic field on the wire?

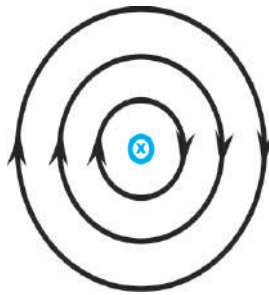
Right hand rule helps you to find the direction of magnetic force exerted by the magnetic field on current carrying wire. It does not help you explain the reason for deflection of wire.

- Can you give a reason for it?

Imagine a situation where there is no current in the wire. Then there exists only magnetic field due to external source (horse shoe magnet). When there is a current in the wire, it also produces a magnetic field. These fields overlap and give non- uniform field. Let us see this clearly with diagrams.



*fig-11(a): Field lines due to horseshoe magnet between its poles*



*fig-11(b): Current into the page*



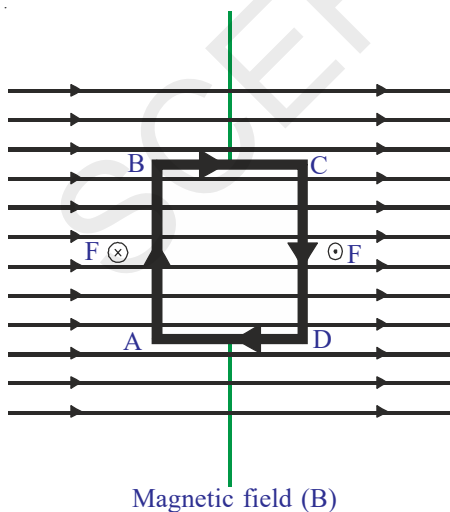
*fig-11(c)*

The field in between north and south pole of horse shoe magnet is shown in the figure 11 (a). Let us imagine a wire passing perpendicular to the paper. Let the current pass through it (into the page). It produces a magnetic field as shown in figure 11(b). Now let us try to sketch the resultant field by observing the field lines. We can see that the direction of the field lines due to the wire in upper part (of circular lines) coincides with the direction of the field lines of horse shoe magnet. The direction of field lines by wire in lower part (of circular lines) is opposite to the direction of the field lines of horse shoe magnet. So that the net field in upper part is strong and in lower part it is weak. Hence a non-uniform field is created around the wire. This non uniform field is shown in figure 11 (c). Therefore the wire tries to move to the weaker field region.

- Does this deflection fit with the direction of magnetic force found by right hand rule?
- What happens when a current carrying coil is placed in a uniform magnetic field?
- Can we use this knowledge to construct an electric motor?

Let us try to answer.

### Electric Motor



*fig-12(a)*

To understand the working of an electric motor we need to understand the behaviour of a current carrying coil kept in a uniform magnetic field.

Consider a rectangular coil kept in a uniform magnetic field as shown in figure 12(a). Switch on the circuit so that the current flows through the rectangular coil. The direction of current in the coil is shown in figure 12(a).

- What is the angle made by AB and CD with magnetic field?

You will notice that they are always at right angles to the magnetic field.

- Can you draw the direction of magnetic force on sides AB and CD?  
Apply right hand rule to get the direction of magnetic force. At AB, the magnetic force acts inward perpendicular ( $F \otimes$ ) to field of the magnet and on CD, it acts outward ( $F \odot$ ).

The force on the sides BC and DA varies because they make different angles at different positions of the coil in the field.

- What are the directions of forces on BC and DA?

In the direction of currents in BC and DA are parallel to the field. magnetic force does't act on them. If the direction of currents in BC and DA are perpendicular to the field at BC, magnetic force pulls the coil up and at DA magnetic force pulls it down.

- What is the net force on the rectangular coil?

The force on AB is equal and opposite to the force on CD due to external magnetic field because they carry equal currents in the opposite direction. Sum of these forces is zero; similarly the sum of the forces on sides BC and DA is also zero for the same reason. So, net force on the coil is zero. But there is rotation of the coil. How is it possible?

- Why does the coil rotate?

Let us consider opening a cap of the bottle as an example where two equal and opposite forces act on the cap. Two forces equal in magnitude but opposite in direction must act on the either side of cap of the bottle as shown in figure 12 (b). These forces bring the cap into rotation. Similarly the rectangular coil comes into rotation in clockwise direction because of equal and opposite pair of forces acting on the two sides of the coil.

- What happens to the rotation of the coil if the direction of current in the coil remains unchanged?

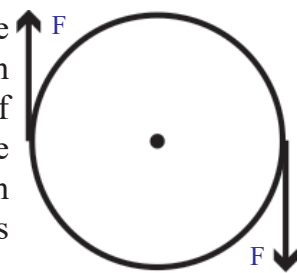
If the direction of current in the coil is unchanged, it rotates up to a vertical position then due to its inertia it rotates further in clockwise direction. But now the sides of the coil experience forces which are in the opposite direction to the previous case. Hence these forces try to rotate it in anti clockwise direction. As a result, this coil comes to halt and rotates in anti clock wise direction, this will go on if the direction of current remains unchanged.

- How could you make the coil rotate continuously?

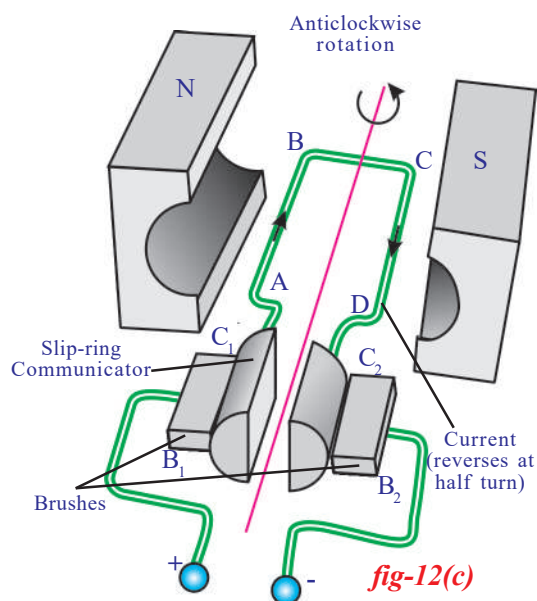
If the direction of current in the coil, after the first half rotation, is reversed, the coil will continue to rotate in the same direction. Thus if the direction of current through the coil is reversed every half rotation, the coil will rotate continuously in one and the same direction.

- How can we achieve this?

To achieve this, brushes  $B_1$  and  $B_2$  are used, as shown in figure 12 (c). These brushes are connected to the battery. The ends of the coil are



*fig-12(b)  
Couple action on  
bottle cap*



connected to slip rings  $C_1$  and  $C_2$ , which rotate along with the coil. Initially  $C_1$  is in contact with  $B_1$  and  $C_2$  is in contact with  $B_2$ . After half rotation, the brushes come into contact with the other slip rings in such a way that the direction of current through the coil is reversed. This happens every half rotation. Thus the direction of rotation of the coil remains the same. This is the principle used in “electric motor.”

In electric motors, electrical energy is converted into mechanical energy.

We have learned that a current carrying coil rotates when it is kept in a uniform magnetic field.

- What happens when a coil without current is made to rotate in magnetic field?
- How is current produced?

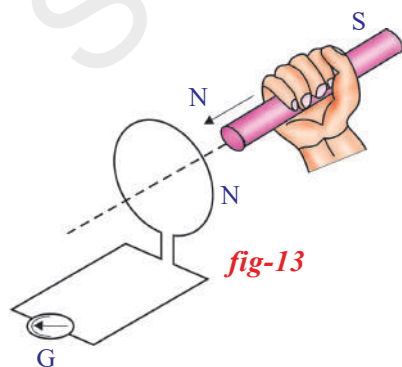
### **(?) Do you know?**

- The relation between direction of induced current, magnetic field and force can also be explained by Fleming's left hand rule. Stretch the left hand thumb, middle finger and forefinger in such a way that they are mutually perpendicular to each other. The forefinger indicates the direction of magnetic field, the middle finger indicates the direction of current and thumb indicates direction of force. By using the Fleming's left hand rule we can explain the working of electric motor.

## **Electromagnetic induction**

### **Activity 9**

The discovery and understanding of electromagnetic induction are based on a long series of experiments carried out by Faraday and Henry. Let us try to do one of those experiments.



Connect the terminals of a coil to a sensitive ammeter or a galvanometer as shown in the fig.-13. Normally, we would not expect any deflections of needle in the galvanometer because there is no electromotive force in this circuit. Now if we push a bar magnet towards the coil, with its north pole facing the coil, a remarkable thing happens. While the magnet is moving towards the coil, the needle in galvanometer deflects, showing that a current has been set up in the coil, the galvanometer does

not deflect if the magnet is at rest. If the magnet is moved away from the coil, the needle in the galvanometer again deflects, but in the opposite direction, which means that a current is set up in the coil in the opposite direction.

If we use the end of south pole of a magnet instead of north pole in the above activity, the experiment works just as described but the deflections are exactly reversed.

Further experimentation enables us to understand that the relative motion of the magnet and coil set up a current in the coil. It makes no difference whether the magnet is moved towards the coil or the coil towards the magnet.

### Faraday's Law

“Whenever there is a continuous change of magnetic flux linked with a closed coil, a current is generated in the coil.”

This is one form of Faraday's law.

The current generated is called induced current and is set up by an induced electromotive force (induced EMF). This phenomenon of getting induced current is called electromagnetic induction.

Faraday observed that the changes in the magnetic flux through the coil are responsible for the generation of current in the coil. He also observed that the rapid changes in flux through coil generate greater induced current or induced EMF. After observing this important factor, he proposed a law of electromagnetic induction, which is as follow,

“The induced EMF generated in a closed loop is equal to the rate of change of magnetic flux passing through it.”

In mathematical form, we can write this as

$$\text{Induced EMF} = \frac{\text{change in flux}}{\text{time}}$$

$$\varepsilon = \frac{\Delta\Phi}{\Delta t} \dots\dots\dots(6)$$

The equation is called Faraday's law of induction where  $\Phi$  (phi) is the flux linked with coil. Let  $\Phi_0$  be the flux linked with single turn. If there are N turns in the coil, the flux linked with the coil is  $N \Phi_0$ .

$$\Phi = N \Phi_0 \dots\dots\dots(7)$$

So far we have not specified the direction of the induced EMF or induced current. In the previous example, we have observed that an induced current is set up in the loop.

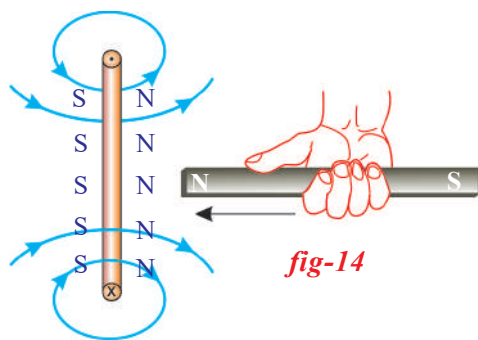
- What is its direction?
- Can you apply conservation of energy for electromagnetic induction?

## Lenz Law

When we push the bar magnet towards the coils, current is generated, in other word electromagnetic induction takes place and mechanical energy is converted into electrical energy.

Let us discuss it in detail.

We know that when a bar magnet is pushed towards a coil with its north pole facing the coil an induced current is set up in the coil. Let the direction of current in the coil be in clockwise direction with respect to north pole of the bar magnet. Then this current carrying loop behaves like a magnet, with its south pole facing the north pole of bar magnet. In such a case, the bar magnet attracts the coil. Then it gains kinetic energy. This is contradictory to conservation of energy. So our assumed clockwise direction of



induced current is wrong. Hence the correct direction of induced current has to be in anticlockwise direction with respect to north pole of the bar magnet. In such a case, the north pole of the coil faces the north pole of the bar magnet as shown in figure 14. Then north pole of bar magnet is repelled by the north pole of the coil. Hence we need to do work to overcome this force. This work done on the magnet is converted into electrical energy in the coil. In this way conservation of energy takes place in electromagnetic induction.

Let us see a case where the bar magnet is pulled away from the coil, with north pole facing the coil. In such case, the coil opposes the motion of bar magnet to balance the conversion of mechanical energy into electric energy. This happens only when the north pole of the magnet faces the south pole of the coil.

- Can you guess what could be the direction of induced current in the coil in such case?

Invariably the direction of induced current in the coil must be in anti clock wise direction. In simple terms, when flux increases through coil, the coil opposes the increase in the flux and when flux decreases through coil, it opposes the decrease in the flux. This is discovered by a Russian Physist **Heinrich Lenz**.

Lenz's law states that "the induced current will appear in such a direction that it opposes the changes in the flux in the coil."

- Could we get Faraday's law of induction from conservation of energy?

## Derivation of Faraday's Law

Let us arrange an apparatus as shown in figure 15. It consists of a pair of parallel bare conductors which are spaced  $l$  meters apart in uniform magnetic field of 'B'. We can hold another bare conductor in such a way that it is in contact with the two parallel wires (see figure-15). A galvanometer is connected to the ends of parallel conductors to complete an electric circuit. Now if the cross wire (cross conductor) placed across parallel conductors is moved to the left, galvanometer needle will deflect in one direction.

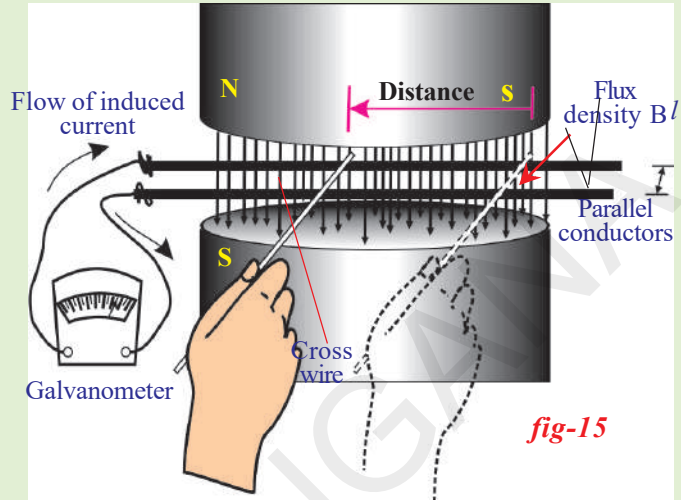


fig-15

If this cross wire is moved to the right, its needle deflects in a direction opposite to the previous deflection. Suppose that the crosswire is moved to the left to a distance of 's' meters in a time of ' $\Delta t$ '. Then the reading of galvanometer gives us the amount of current that flows in the circuit. A current will be set up in the circuit only when there is an EMF in the circuit. Let this EMF be ' $\epsilon$ '. The principle of conservation of energy tells us that this electric energy (associated with flow of current) must come from the work that we have done in moving the crosswire. If we ignore friction everywhere, in the arrangement, the work done by this applied force =  $Fs$ . It is evident that there is a current of 'I' amperes flowing through the length of  $l$  meters of the cross wire, and the cross wire is in a magnetic field. With this information,

- Can you derive an expression for the force applied on crosswire by the field B?

We know that it is equal to  $BIl$ , from equation-4 of previous discussion (see page 220).

$$\text{i.e., } F = BIl \quad \dots\dots\dots(8)$$

This force must oppose the applied force. The direction of applied force determines the direction of current through the cross wire. Here we are doing positive work. The work done by us in moving the cross wire converts into electric energy. So the work done is given by,

$$W = Fs = BIls \quad \dots\dots\dots(9) \quad (\text{using equation-8})$$

When we put the cross wire across parallel conductors it makes a complete electrical circuit which encloses a certain amount of magnetic

flux. Now as we move the cross wire to the left, the area of the loop (formed by the parallel conductors and cross wire) decreases and the flux through the loop also decreases. The decrease in flux is given by,

$$\Delta\Phi = B\Delta s \quad \dots\dots\dots(10)$$

Here B is perpendicular to the area ( $\Delta s$ ). From equations 9 and 10

$$W = (\Delta\Phi) I$$

Let us divide both sides of this equation by  $\Delta t$

$$\frac{W}{\Delta t} = \frac{I \Delta\Phi}{\Delta t} \quad \dots\dots\dots(11)$$

$$\text{Electric power, } P = \frac{I \Delta\Phi}{\Delta t}$$

We know that electric power is the product of current and emf or voltage.  $\epsilon = \frac{\Delta\Phi}{\Delta t}$  is obviously equal to induced EMF.

$$\text{Electric power, } P = \epsilon I \quad \dots\dots\dots(12)$$

Thus the electric power generated in the circuit is equal to product of induced EMF and the current. Thus the mechanical energy utilised to move the cross wire in one second is converted into electric power  $\frac{\Delta\Phi}{\Delta t} I$ . This is nothing but conservation of energy.

Dividing equation (9) by  $\Delta t$ , we have

$$\frac{W}{\Delta t} = \frac{F\Delta s}{\Delta t} = \frac{BI\Delta s}{\Delta t} \quad \dots\dots\dots(13)$$

Here  $\frac{\Delta s}{\Delta t}$  gives the speed of the cross wire, let it be taken as v. Then we

$$\text{get, Electric power } P = \frac{W}{\Delta t} = Fv = BIv \quad \dots\dots(14)$$

Power is also given as force times velocity. From equations (12) and

$$(14), \text{ we get } \frac{W}{\Delta t} = \epsilon I \Rightarrow \epsilon I = BIv$$

We get,

$$\epsilon = Bv \quad \text{This is called motional EMF.}$$

The above equation is not Faraday's law of induction because it is not related to the loop. It is useful when a conductor moves in a uniform magnetic field.

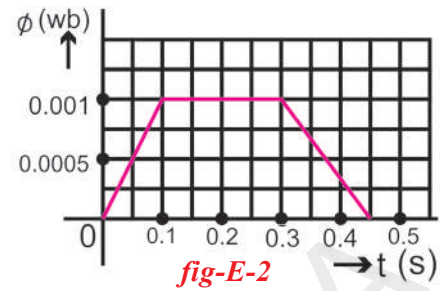


Let us see a few examples on induced emf.

### Example 1

The magnetic flux inside a coil of 400 turns changes for each single turn with time as shown in figure

Determine the maximum induced emf generated in the coil. Is there any change in induced EMF from  $t = 0.1$  second to 0.3 second?



**Solution:** From the given graph, the increase in magnetic flux through one turn of coil in 0.1 second is 0.001 Wb. According to Faraday's law, the maximum induced emf generated in the coil is given by,

$$\varepsilon = N \frac{\Delta\Phi}{\Delta t}$$

Substituting the values, we get

$$\varepsilon = \frac{400 \times 0.001}{0.1} = 4V$$

From graph, there is no change in magnetic flux through coil from  $t = 0.1s$  to  $0.3s$  hence no emf is generated.

### Example 2

Find the length of the conductor which is moving with a speed of 10 m/s in the direction perpendicular to the direction of magnetic field of induction 0.8T, if it induces an emf of 8V between the ends of the conductor.

**Solution:** Given that  $B = 0.8T$ ,  $v = 10$  m/s and  $\varepsilon = 8V$ .

Using  $\varepsilon = Blv$

$$8 = 0.8(l)(10)$$

$$l \text{ (length of the conductor)} = 1m$$

### Applications of Faraday's law of electromagnetic induction

Electromagnetic induction is all around us.

- You might have seen that, during security check, people are made to walk through a large upright coil of wire which produces a weak AC (alternating) magnetic field. If we are carrying any significant quantities of iron, the magnetic flux linked with the large coil changes and the induced current generated in coil triggers an alarm.
- The tape recorder which we use to listen to songs (or) record voices works on the principle of electromagnetic induction. It consists of a piece of plastic tape coated with iron oxide and is magnetised more in

some parts than in others. When the tape is moved past as a small coil of wire (head of the tape recorder), the magnetic field produced by the tape changes, which leads to generation of current in the small coil of wire.

- How could we use the principle of electromagnetic induction in the case of using ATM card when its magnetic strip is swiped through a scanner? Discuss with your friends and your teacher.
- An induction stove works on the principle of electromagnetic induction. A metal coil is kept just beneath the cooling surface. It carries alternating current (AC) so that AC produces an alternating magnetic field. When you keep a metal pan with water on it, the varying magnetic field beneath it crosses the bottom surface of the pan and an EMF is induced in it. Because the pan is metal the induced EMF generates an induced current in it. Since the pan has a finite resistance, the flow induced current in it produces heat in it and this heat is conducted to the water. That's why we call this stove as induction stove.

Have you ever thought, from where do we get electrical energy?

Let us learn about it.

### Magnetic Levitation

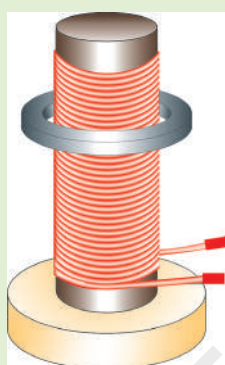


fig-16(a)

Take a wooden base as shown in figure 16(a). Fix a soft iron cylinder on the wooden base vertically. Wind copper wire around the soft iron as shown in figure 16(a). Now take a metal ring which is slightly greater in radius than the radius of the soft iron cylinder and insert it through the soft iron cylinder on the wooden base. Connect the ends of the coil to an AC source and switch on the current.

- What do you notice?

You notice that the metal ring is levitated on the coil.

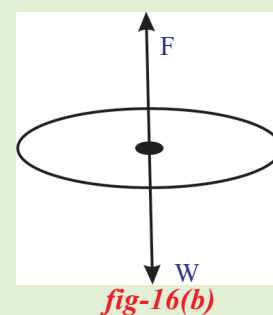
Switch off the current, the ring will jump into the air very dramatically. Remove the AC supply and connect a DC supply. Observe what happens.

- Why is there a difference in behaviour in these two cases?
- What force supports the ring against gravity when it is being levitated?
- Could the ring be levitated if DC is used?

The metal ring levitates when AC is used, therefore the net force on it should be zero according to Newton's second law. The free body diagram of metal ring is shown in figure 16 (b). Weight ( $w$ ) acts down. To balance it, a force ( $F$ ) equal in magnitude and opposite in direction should act as shown in figure 16 (b).

- What is this unknown force acting on the metal ring?

In this activity AC is used. AC changes both its magnitude and direction in regular time intervals. We know that the current through the coil, produces a magnetic field so that one end of the coil behaves like north pole and other end behaves like south pole for a certain time interval. For the next interval, coil changes its polarities. Hence we can say that coil undergoes changes in its poles in the same intervals of time. The levitation of metal ring is possible only when the metal ring behaves like a magnet and should change its polarities in the same time intervals but in a sense opposite to that of the solenoid (coil) as shown in figure 16(c). Assume that the current flows in an clockwise direction in the solenoid as viewed from the top. Then the upper end becomes a south pole. An upward force is applied on the ring only when the upper side of the ring becomes a north pole (i.e. south pole of the ring faces towards the south pole of solenoid). It is only possible when there exists a anticlockwise current (viewed from the top) in the ring. After certain intervals, solenoid changes its polarities, so that the ring should also change its polarities in the same intervals. This is the reason why the metal ring is levitated.



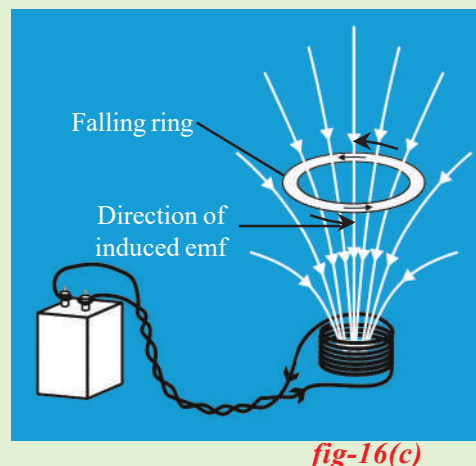
- What is responsible for the current in the metal ring?

AC is not a constant current. So that, the magnetic induction changes in both magnitude and direction in the solenoid and in the ring.

Here the area of the metal ring is constant. But the field through the metal ring changes so that flux linked with the metal ring changes.

- If DC is used, the metal ring lifts up and falls down immediately. Why?

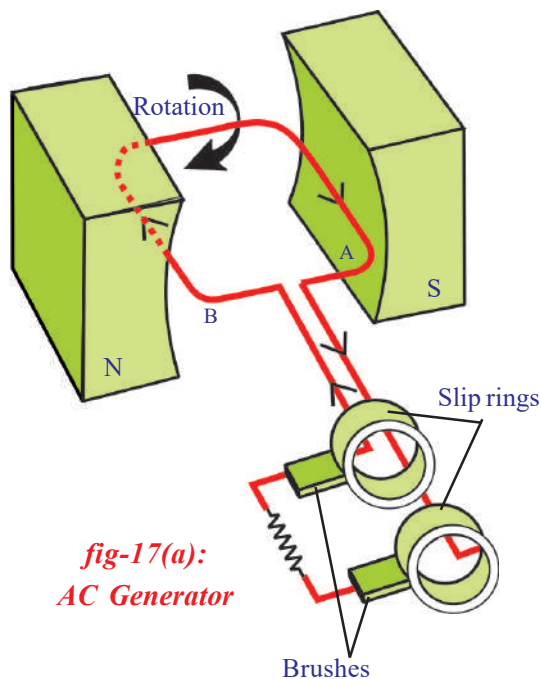
The flux linked with metal ring is zero when no current flows through the solenoid. When the current is allowed to flow through the solenoid, it behaves like bar magnet. So the flux is linked to the metal ring when the switch is on. At that instant there is a change in flux linked with ring. Hence the ring rises up. There after, there is no change in flux linked with coil, hence it falls down. If the switch is off, the metal ring again lifts up and falls down. In this case also, there is a change in flux linked with ring when the switch is off.



- What could you conclude from the above analysis?

## Electric Generator and Alternating - Direct Currents

- What happens when a coil is continuously rotated in a uniform magnetic field?
- Does it help us to generate electric current?



**fig-17(a):**  
**AC Generator**

Let us see:

Consider a rectangular coil. Let it be held between the poles of Curve-shaped permanent magnet as shown in fig.-17(a). As the coil rotates, the magnetic flux passing through the coil changes. According to the law of electro magnetic induction an induced current is generated in the coil.

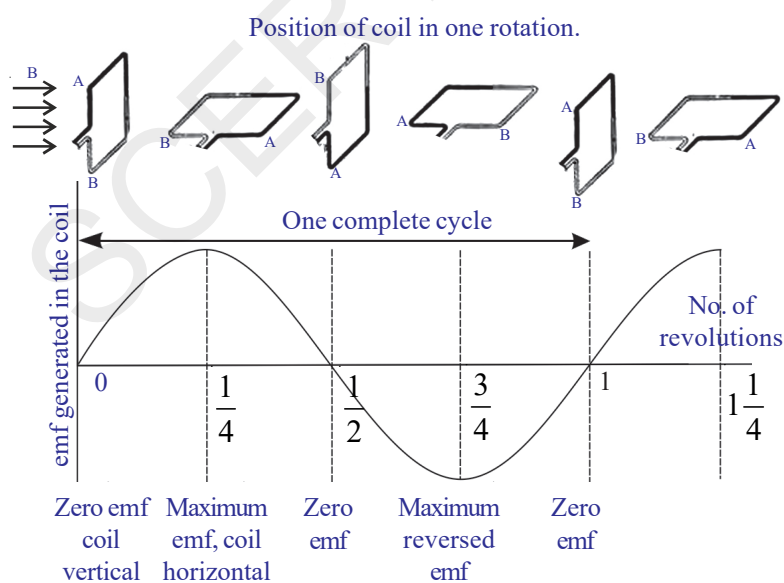
- Is the direction of current induced in the coil constant? Does it change?

1. Consider initially the coil, positioned in such a way that magnetic flux passes through it. When the coil is at rest in vertical position, with side A of coil at top position and side B at bottom position, no current will be induced in it. Thus current in the coil is zero at this position.

2. When the coil is rotated in clockwise direction, current will be induced in it and it flows from A to B. During the first quarter of rotation, the current increases from zero to a maximum and reaches peak value when the coil is in horizontal position.

3. If we continue the rotation of coil, current decreases during the second quarter of the rotation and once again becomes zero when coil comes to vertical position with side B at top A at bottom position. During the second part of the rotation, current generated follows the same pattern as that in the first half except that the direction of current is reversed.

(see fig.-17(b))



**fig-17(b)**

- Can you guess the reason for variation of current from zero to maximum and vice-versa during the rotation of coil?
- Can we make use of this current? If so, how?

Let us find out.

As shown in fig.-17(a) the ends of the coil are connected to two slip rings. Two carbon brushes arranged in such a way that

they press the slip rings to obtain current from the coil. When these brushes are connected to external devices like TV, radio, we can make them work with current supplied from ends of carbon brushes.

The current obtained by this process changes its direction alternatively for each half cycle as shown in fig.-17(b).

This current is called alternating current (AC) in which, the direction of charge flow reverses periodically. So AC possesses certain frequency. The generator that we discussed here is called AC generator.

- How can we get DC current using a generator?
- What changes do we need to make in an AC generator to be converted into a DC generator?

Let us find out.

If two half slip rings are connected to ends of the coil as shown in fig.-17(c), the AC generator works as DC generator to produce DC current.

Let us see how it works.

When the coil is in the vertical position the induced current generated during the first half rotation, rises from zero to maximum and then falls to zero again. As the coil moves further from this position, the ends of the coil go to other slip rings. Hence during the second half rotation, the current is reversed in the coil itself, the current generated in the second half rotation of the coil is identical with that during the first half of direct current (DC) as shown in fig.-17(d) for one revolution.

In generators, mechanical energy is converted into the electrical energy.

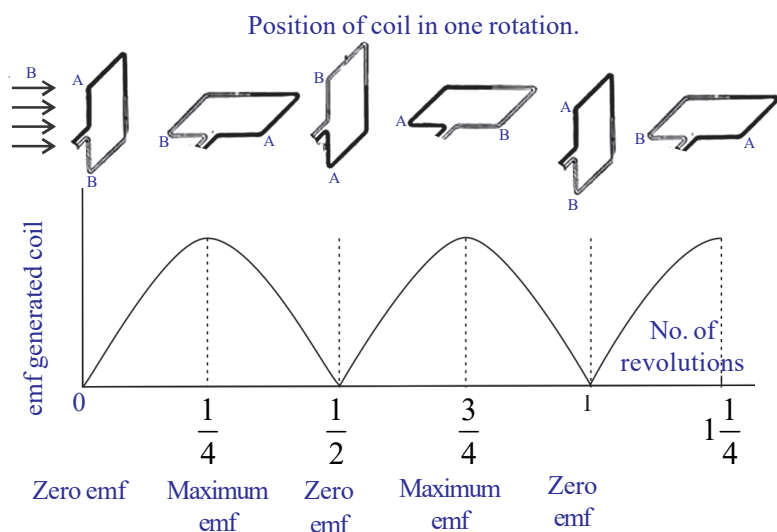
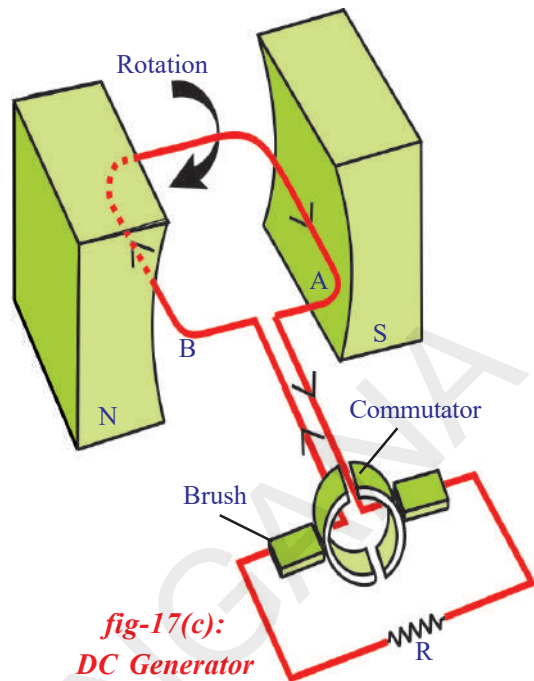


fig-17(d)



## Key words

*Magnetic flux, Magnetic flux density, Electric motor, Slip rings, Induced current, Induced EMF, Electric generator, DC and AC currents, rms values*



## What we have learnt

- A measure of strength of magnetic flux by taking account of number of field lines is called magnetic flux.
- Magnetic flux density (B) is defined as the ratio of flux passing through a plane perpendicular to field and the area of the plane.
- Current carrying wire produces magnetic field.
- $F = qvB \sin \theta$  and  $F = ILB \sin \theta$
- In electric motor, electrical energy is converted into mechanical energy.
- The production of electric current due to relative motion between a coil and a magnetic field is called electromagnetic induction.
- Faraday's law: The induced EMF generated in a closed loop is equal to the rate of change of magnetic flux passing through it.
- Lenz's law: the induced current set up in the coil is in such a direction that it opposes the changes in the flux.
- When a conductor of length ' $l$ ' moves perpendicular to field B with a speed v then potential difference (voltage) developed between the ends of conductor is  $B/v$ . This EMF is called motional EMF.
- In generators, mechanical energy is converted into electrical energy.



## Improve your learning

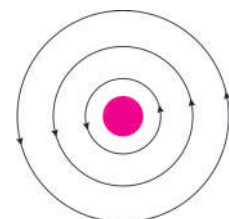


fig- Q2

### Reflections on Concepts

1. Are the magnetic field lines closed? Explain. (AS<sub>1</sub>)
2. See fig-Q2, magnetic lines are shown. What is the direction of the current flowing through the wire?(AS<sub>1</sub>)
3. A bar magnet with North Pole facing towards a coil moves as shown in fig-Q3. What happens to the magnetic flux passing through the coil? (AS<sub>1</sub>)

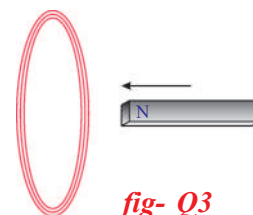


fig- Q3

4. A coil is kept perpendicular to the page. At P, current flows into the page and at Q it comes out of the page as shown in fig-Q3. What is the direction of magnetic field due to the coil?(AS<sub>1</sub>)



fig- Q4

### Application of Concepts

- The direction of current flowing in a coil is shown in fig-Q. What type of magnetic pole is formed at the face that has flow of current as shown in fig-Q? (AS<sub>1</sub>)
- Why does the picture appear distorted when a bar magnet is brought close to the screen of a television? Explain (AS<sub>1</sub>)
- Symbol 'X' in fig.Q3 indicates the direction of a magnetic field into the page. A straight long wire carrying current along its length is kept perpendicular to the magnetic field. What is the magnitude of force experienced by the wire? In what direction does it act? (AS<sub>1</sub>)
- An 8N force acts on a rectangular conductor 20cm long placed perpendicular to a magnetic field. Determine the magnetic field induction if the current in the conductor is 40A. (Ans: 1tesla) (AS<sub>1</sub>)
- As shown in the fig-Q5, both coil and bar magnet moves in the same direction. What happens? (AS<sub>2</sub>)
- Give a few applications of Faraday's law of induction in daily life. (AS<sub>7</sub>)



fig- Q

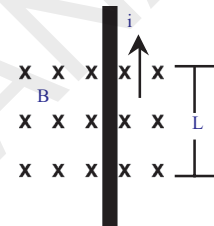


fig- Q3

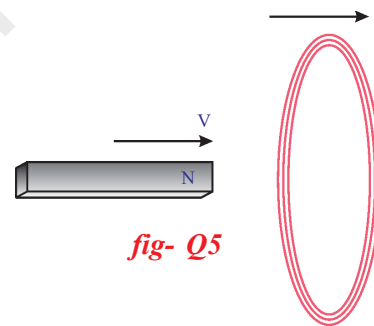


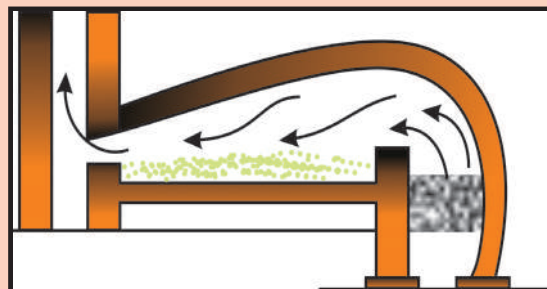
fig- Q5

### Multiple choice questions

- Which of the following converts electrical energy into mechanical energy [     ]
  - motor
  - battery
  - generator
  - switch
- Which of the following converts mechanical energy into electrical energy [     ]
  - motor
  - battery
  - generator
  - switch
- The magnetic force on a current carrying wire placed in uniform magnetic field if the wire is oriented perpendicular to magnetic field is [     ]
  - 0
  - ILB
  - 2ILB
  - $\frac{ILB}{2}$







# Principles of Metallurgy

In class 8 you have studied about certain properties of metals like, malleability, ductility, sonority etc. Metals play an important role in our daily life. We use various metals for various purposes like gold and silver as jewellery, copper, iron, aluminium for making conducting wires and for making utensils etc. We use many house hold articles made up of metals and their alloys at our home.

- Can you mention some articles that are made up of metals?
- Do metals exist in nature in the same form as that we use in our daily life?
- Have you ever heard the words like ore, mineral and metallurgy?
- Do you know how these metals are obtained?

To understand these questions you need to know about metallurgy. In this chapter we discuss various concepts related to metallurgy and the process by which we are able to obtain the pure form of metal that we use in our daily life.

“**Metallurgy** is the process of extraction of metals from their ores”.

Human history in terms of materials had the Bronze Age and Iron Age pertaining to the metals they started to use the bronze (an alloy of copper and tin) and iron. Now we have more than 75% metals among the elements available.

## Occurrence of the metals in nature

- How the metals are present in nature?

The earth’s crust is the major source of metals. Sea water also contains some soluble salts such as sodium chloride and magnesium chloride etc.

Some metals like gold (Au), silver (Ag) and copper (Cu) are available in nature in free state (native) as they are least reactive. Other metals mostly are found in nature in the combined form due to their more reactivity. The elements or compounds of the metals which occur in nature in the earth crust are called *minerals*. At some places, minerals contain a very high percentage of a particular metal and the metal can be profitably extracted from it. The minerals from which the metals are extracted without economical loss are called *ores*.

Aluminium, for example, is the most common metal in the Earth's crust, occurring in most of minerals. However, it isn't economically feasible to extract it from most of these minerals. Instead, the usual ore from which it is profitable to extract it is bauxite – which contains from 50 – 70 % of aluminium oxide .



### Think and discuss

- Do you agree with the statement “All ores are minerals but all minerals need not be ores?” Why?

### Activity 1

Look at the following ores.  
Identify the metal present in each ore.

Table - 1

ORE	Formula	metal	ORE	Formula	metal
Bauxite	$\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$	Al	Zincite	ZnO	Zn
Copper Iron Pyrites	$\text{CuFeS}_2$	Cu	Rock salt	NaCl	Na
Zinc Blende	ZnS	Zn	Cinnabar	HgS	Hg
Magnesite	$\text{MgCO}_3$	Mg	Magnetite	$\text{Fe}_3\text{O}_4$	Fe
Epsom salt	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	Mg	Galena	PbS	Pb
Horn Silver	AgCl	Ag	Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Ca
Pyrolusite	$\text{MnO}_2$	Mn	Lime stone	$\text{CaCO}_3$	Ca
Haematite	$\text{Fe}_2\text{O}_3$	Fe	Carnallite	$\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	Mg

Now try to classify them as shown in the table.

**Table - 2**

Oxides	Sulphides	Chlorides	Carbonates	Sulphates

- What metals can we get from the ores mentioned in the Table – 1?
- Can you arrange these metals in the order of their reactivity?
- What do you notice in Table – 2?

You will notice that the ores of many metals are oxides and sulphides. This is why oxygen - sulphur (16<sup>th</sup> group) group is called chalcogen family (*chalco = ore; genus = produce*)

The metals like K, Na, Ca, Mg and Al are so reactive that they are never found in nature in free state.

The metals like Zn, Fe, Pb etc., are moderately reactive. They are found in the earth crust mainly as oxides, sulphides and carbonates.

Metals like Au, Ag are least reactive and they are found even in free state in nature.

Based on reactivity we can arrange metal in descending order of their reactivity as shown below:

<b>K, Na, Ca, Mg, Al</b>	<b>Zn, Fe, Pb, Cu</b>	<b>Hg, Ag, Pt, Au</b>
High reactivity	Moderate reactivity	Low reactivity

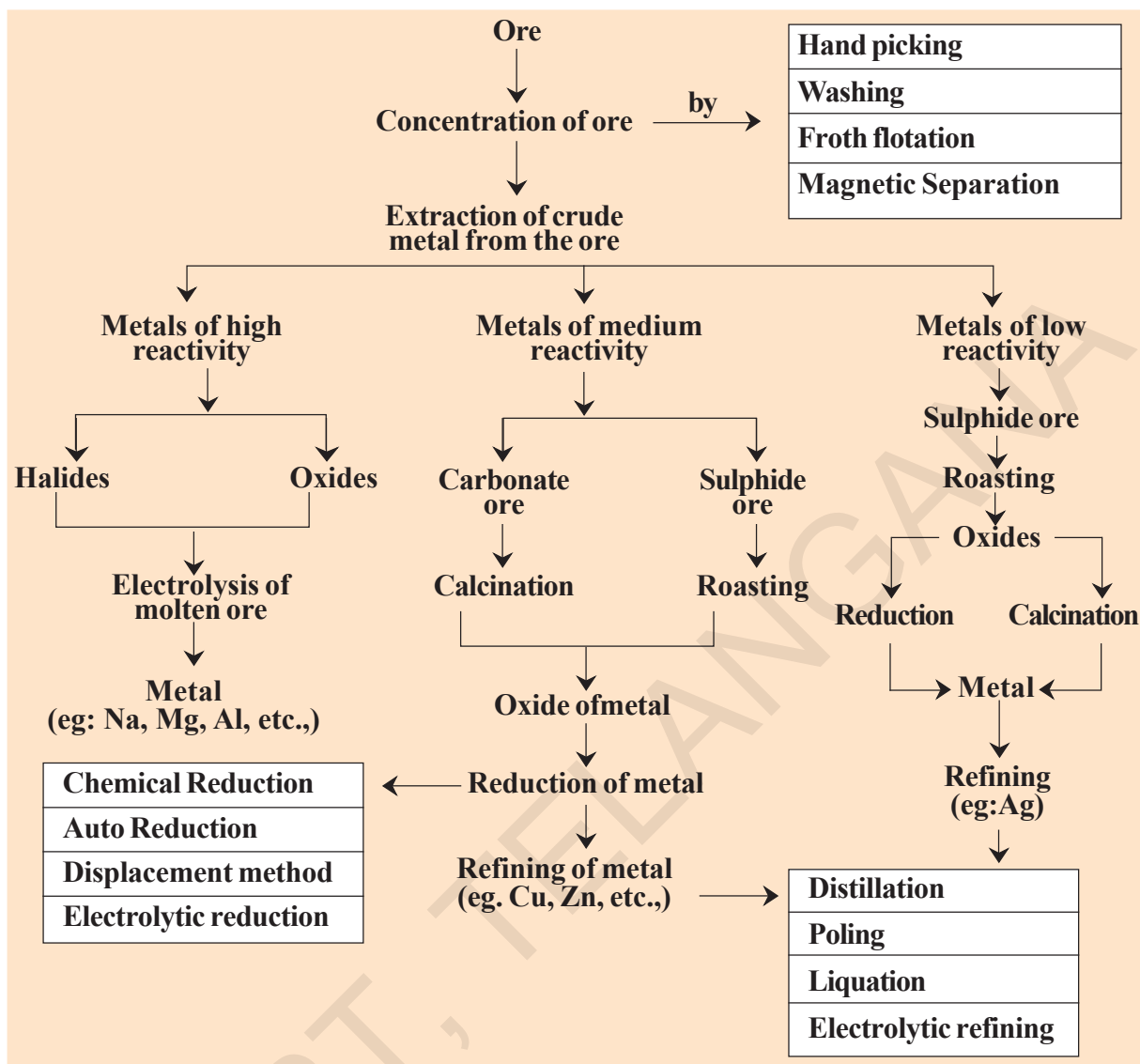
- Can you think how do we get these metals from their ores?
- Does the reactivity of a metal and form of its ore (oxides, sulphides, chlorides, carbonates sulphates) has any relation with process of extraction?
- How are metals extracted from mineral ores?
- What methods are to be used?

Let us find.

### Extraction of metals from the ores:

The extraction of a metal from its ore involves mainly three stages. They are:

- I) Concentration or Dressing
- II) Extraction of crude metal
- III) Refining or purification of the metal.



## I. Concentration or Dressing of the ore

Ores that are mined from the earth are usually contaminated with large amount of impurities such as soil and sand etc.

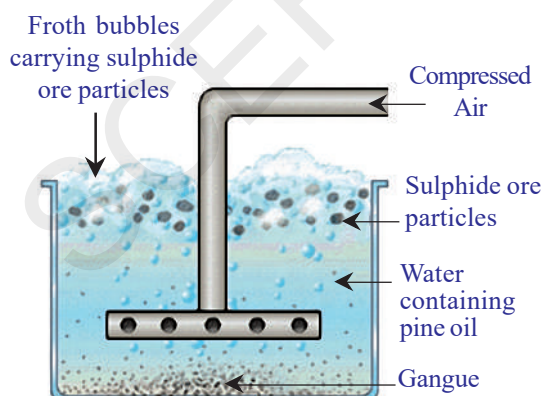
Concentration or Dressing means, simply getting rid of as much of the unwanted rocky material as possible from the ore. The impurities like sand and clay are called *gangue*. Here, we should get as for as possible pure or more concentrated ore.

*Enrichment (concentration) of the ore:* Various physical methods are used to enrich the ore. In many cases, it is possible to separate the metal compound from unwanted rocky material by physical means. An example for this is *froth flotation*.

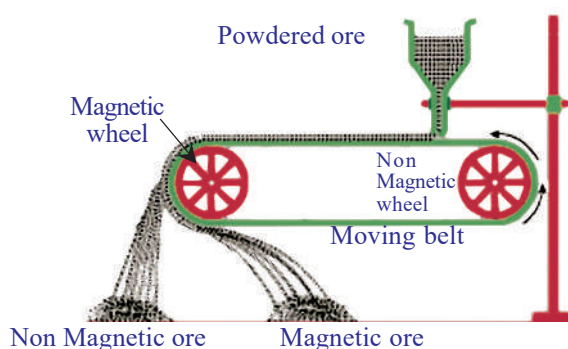
The physical methods adopted in dressing of the ore (or) enriching of the ore depends upon difference between physical properties of ore and gangue.

**Table-3**

Name of the method	Process
<b>Hand picking</b>	If the ore particles and the impurities are different in one of the properties like colour, size etc., Using that property the ore particles are handpicked separating them from other impurities.
<b>Washing</b>	Ore particles are crushed and kept on a slopy surface. They are washed with controlled flow of water. Less dense impurities are carried away by water flow, leaving the more dense ore particles behind.
<b>Froth flotation</b>	This method is mainly useful for sulphide ores which have no wetting property whereas the impurities get wetted. The ore with impurities is finely powdered and kept in water taken in a flotation cell. Air under pressure is blown to produce froth in water. Froth so produced, takes the ore particles to the surface whereas impurities settle at the bottom. Froth is separated and washed to get ore particles.(see fig.1)
<b>Magnetic separation</b>	If the ore or impurity, one of them is magnetic substance and the other non-magnetic substance they are separated using electromagnets. (see Fig.2)



**fig-1: Froth flotation process for the concentration of sulphide ores**



**fig-2: Magnetic separation**

There are some other methods also for dressing which you will learn at higher classes

# Reactivity of Metals

Table-4

Metals	Action of Oxygen	Reaction with cold water	Reaction with steam	Reaction with dilute strong Acids	Reaction with chlorine on heating
K	Form $\text{Na}_2\text{O}$ , $\text{K}_2\text{O}$ in limited supply of $\text{O}_2$ but form peroxides in excess of $\text{O}_2$	K to Mg displace $\text{H}_2$ from cold water with decreasing reactivity {K violently but Mg very slowly}	K to Fe displace $\text{H}_2$ with steam without decreasing reactivity. {K very violently but Fe very slowly}	K to Pb displace $\text{H}_2$ from dilute strong acids with decreasing reactivity. {K-explosively, Mg-very vigorously, Fe-steadily, Pb-very slowly}	All metals react with Chlorine on heating to form their respective Chlorides but with decreasing reactivity from top to bottom. This is understood from the heat evolved when the metal reacts with one mole of Chlorine gas to form Chloride.
Na					
Ca	Burn with decreasing vigour to form oxides $\text{CaO}$ , $\text{MgO}$ , $\text{Al}_2\text{O}_3$ , $\text{ZnO}$ , $\text{Fe}_2\text{O}_3$	From Al to Au do not displace $\text{H}_2$ from cold water	From Pb to Au do not displace $\text{H}_2$ from steam	Cu to Au do not displace $\text{H}_2$ from dilute strong acids	$\text{KCl}$ , $\text{NaCl}$ , $\text{CaCl}_2$ , $\text{MgCl}_2$ , $\text{AlCl}_3$ , $\text{ZnCl}_2$ , $\text{FeCl}_3$ , $\text{PbCl}_2$ , $\text{CuCl}_2$ , $\text{HgCl}_2$ , $\text{AgCl}$ , $\text{PtCl}_3$ and $\text{AuCl}_3$ are formed
Mg					
Al					
Zn					
Fe	Don't burn, but only form a surface layer of oxide $\text{PbO}$ , $\text{CuO}$ , $\text{HgO}$				
Pb					
Cu					
Hg	Don't burn or oxidise even on the surface				
Ag					
Pt					
Au					

## II Extraction of crude metal from the ore

Extraction of the metal from its ores depends on the reactivity of the metal. To understand the order of reactivity of metals that are very familiar, we study their chemical reactions with cold water, steam, dilute, strong acids and  $Cl_2$  and based on their vigorous activity order in these reactions we frame out activity series. Arrangement of the metals in decreasing order of their reactivity is known as *activity series*. (See table - 4)

### Reduction of purified ore to the metal

The method used for a particular metal for the reduction of its ore to the metal depends mainly on the position of the metal in the activity series.

#### A) Extraction of Metals at the top of the activity series

(K, Na, Ca, Mg and Al). Simple chemical reduction methods like heating with C, CO etc to reduce the ores of these metals are not feasible. The temperature required for the reduction is too high and more expensive. To make the process economical, electrolysis methods are to be adopted. Again the electrolysis of their aqueous solutions also is not feasible because water in the solution would be discharged at the cathode in preference to the metal ions.

The only method available is to extract these metals by electrolysis of their fused compounds. For example to extract Na from NaCl, fused NaCl is electrolysed with steel cathode (-) and graphite anode (+). The metal (Na) will be deposited at cathode and chloride liberated at the anode.



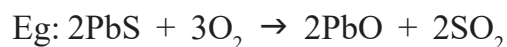
For the above electrolysis, a large quantity of electricity is required to keep the ore in molten state. Suitable impurities are added to the ore to decrease its melting point.

#### B) Extraction of metals in the middle of the activity series

(Zinc, iron, tin, lead and copper): The ores of these metals are generally present as sulphides or carbonates in nature. Therefore prior to reduction of ores of these metals, they must be converted into metal oxides.

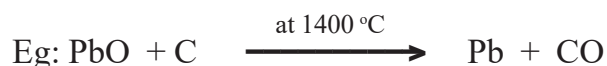
Sulphide ores are converted into oxides by heating them strongly in excess of air. This process is known as *roasting*. Generally the sulphide

ores are roasted to convert them into oxides before reducing them to metal.

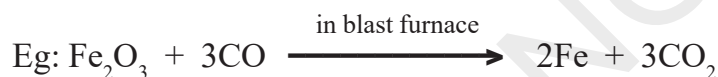


The metal oxides are then reduced to the corresponding metal by using suitable reducing agent such as carbon

**i) Reduction of metal oxides with carbon:** The oxides are reduced by coke in a closed furnace which gives the metal and carbon monoxide (CO).



**ii) Reduction of oxide ores with CO.**



**iii) Auto (self) reduction of sulphide ores:** In the extraction of Cu from its sulphide ore, the ore is subjected partial roasting in air to give its oxide.

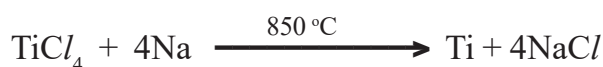
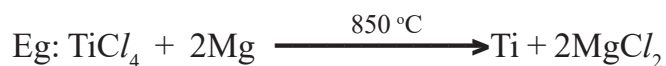


When the supply of air is stopped and the temperature is raised. The rest of the sulphide reacts with oxide and forms the metal and  $\text{SO}_2$ .



**iv) Reduction of ores (compounds) by more reactive metals.**

Thermite process involves the reaction of metal oxides with aluminium. When highly reactive metals such as sodium, calcium, aluminium etc., are used as reducing agents, they displace metals of lower reactivity from the compound. These displacement reactions are highly exothermic. The amount of heat evolved is so large that the metals produced are in molten state.





The reaction of Iron (III) oxide ( $\text{Fe}_2\text{O}_3$ ), with aluminium produces molten iron which is used to join railings of railway tracks or cracked machine parts. This reaction is known as the **thermite reaction**.



fig-3(a)



fig-3(b)



fig-3(c)

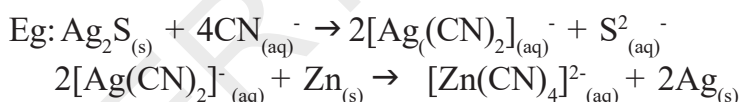
### C) Extraction of metals at the bottom of the activity series (Ag, Hg etc)

Metals at the bottom of the activity series are often found in free state. Their reactivity with other atoms is very low. The oxides of these metals can be reduced to metals by heat alone and sometimes by displacement from their aqueous solutions.

i) When cinnabar ( $\text{HgS}$ ) which is an ore of mercury, heated in air, it is first converted into ( $\text{HgO}$ ) then reduced to mercury on further heating.



ii) Displacement from aqueous solutions:



Here  $\text{Ag}_2\text{S}$  is dissolved in say KCN solution to get dicyanoargentate (I) ions. From these ions Ag is precipitated by treating with Zn dust powder.

### III. Purification of the crude metal

The metal obtained by the reduction of the ore is usually contaminated with impurities like unchanged ore, other metals present in the ore and non metals from the anions in the ore.

For example, the (blister) copper obtained from its sulphide ore, a compound of copper iron pyrites ( $\text{CuFeS}_2$ ), contains some copper sulphide, iron and sulphur. It is purified by suitable methods including electrolysis. The process of obtaining the pure metal from the impure metal is called *refining* of the metal. Refining of the metal involves several types of

processes. Some refining methods are given below:

a) Distillation (b) Poling (c) Liquefaction (d) Electrolysis etc.

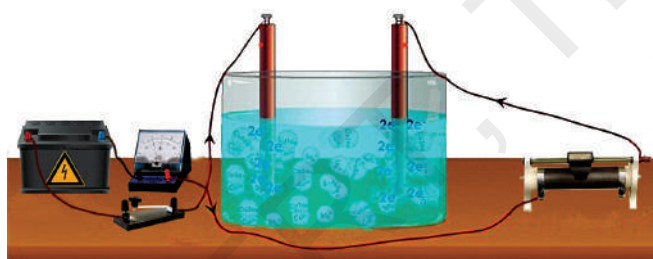
The process that has to be adopted for purification of a given metal depends on the nature of the metal and its impurities.

**a) Distillation:** This method is very useful for purification of low boiling metals like zinc and mercury containing high boiling metals as impurities. The extracted metal in the molten state is distilled to obtain the pure metal as distillate.

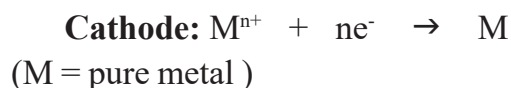
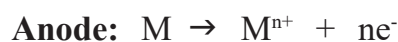
**b) Poling:** The molten metal is stirred with logs (poles) of green wood. The impurities are removed either as gases or they get oxidized and form scum (slag) over the surface of the molten metal. Blister copper is purified by this method. The reducing gases, evolved from the wood, prevent the oxidation of copper.

**c) Liquefaction:** In this method a low melting metal like tin can be made to flow on a slopy surface to separate it from high melting impurities.

**d) Electrolytic refining:** In this method, the impure metal is made to act as anode. A strip of the same metal in pure form is used as cathode. They are put in a suitable electrolytic bath containing soluble salt of the same metal. The required metal gets deposited on the cathode in the pure form. The metal, constituting the impurity, goes as the anode mud. The reactions are:



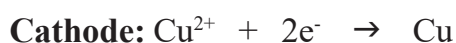
*fig-4: Experimental setup for the electrolytic refining of copper*



Where  $n = 1, 2, 3, \dots$

We use this electrolytic method to refine copper.

For this an impure copper is taken as anode and pure copper strips are taken as cathode. The electrolyte is an acidified solution of copper sulphate. As a result of electrolysis copper in pure form is transferred from the anode to the cathode.



The soluble impurities go into the solution, where as insoluble impurities from the blister copper get deposited at the bottom of anode as anode mud which contains metals like antimony selenium, tellurium, silver, gold and platinum; recovery of these metals may meet the cost of refining.

Zinc may also be refined this way.

## Corrosion

The rusting of iron (iron oxide), tarnishing of silver (silver sulphide), development of green coating on copper (copper carbonate) and bronze are some of the examples of corrosion.

- Do you know why corrosion occurs?

Let us find

### Activity 2

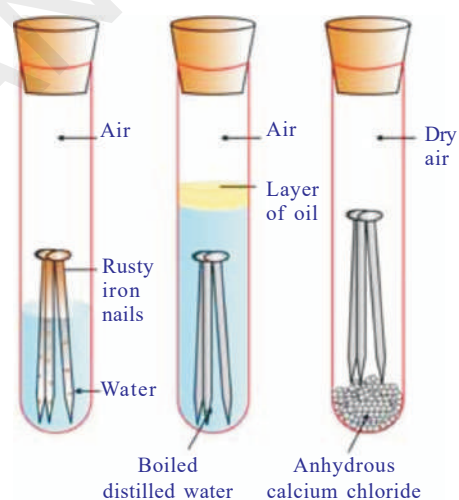
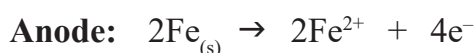
- Take three test tubes and place clean iron nails in each of them.
- Label these test tubes A,B and C. pour some water in test tube A and cork it.
- Pour boiled distilled water in test tube B, add about 1 ml of oil and cork it. The oil will float on water and prevent the air from dissolving in the water.
- Put some anhydrous calcium chloride in test tube C and cork it. Anhydrous calcium chloride will absorb the moisture, if any, from the air. Leave these test tubes for a few days and then observe (see figure).

You will observe that iron nails rust in test tube A, but they do not rust in test tubes B and C. In the test tube A, the nails are exposed to both air and water. In the test tube B, the nails are exposed to only water, and the nails in test tube C are exposed to dry air.

- What does this tell us about the conditions under which iron articles rust?

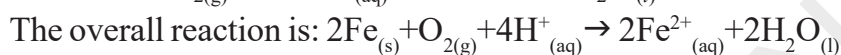
In metallic corrosion, a metal is oxidised by loss of electrons generally to oxygen and results in the formation of oxides. Corrosion of iron (commonly known as rusting) occurs in presence of water and air.

The chemistry of corrosion is quite complex but it may be considered essentially as an electrochemical phenomenon. During corrosion at a particular spot on the surface of an object made of iron, oxidation takes place and that spot behaves as anode. We can write the reaction as.



**fig-5: Investigating the conditions under which iron rusts**

Electrons released at this anodic spot move through the metal and go to another spot on the metal and reduce oxygen at that spot in presence of  $H^+$  (which is believed to be available from  $H_2CO_3$  formed due to dissolution of carbon dioxide from air into water in moist air condition of atmosphere. Hydrogen ion in water may also be available due to dissolution of other acidic oxides from the atmosphere). This spot behaves as cathode with the reaction is.



The Ferrous ions ( $Fe^{2+}$ ) are further oxidised by atmospheric oxygen to Ferric ions ( $Fe^{3+}$ ) which come out as rust in the form of hydrated ferric oxide ( $Fe_2O_3 \cdot xH_2O$ ) and with further production of hydrogen ions.

### Prevention of corrosion

Prevention of corrosion is of prime importance. It not only saves money but also helps in preventing accidents such as a bridge collapse or failure of a key component due to corrosion.

One of the simplest methods of preventing corrosion is to prevent the surface of the metallic object to come in contact with atmosphere. This can be done by covering the surface with paint or by some chemicals (eg: bisphenol).

Another simple method is to cover the surface by other metals (Sn, Zn etc) that are inert or react themselves with atmosphere to save the object. This is generally done by electroplating.

An electrochemical method is to provide a sacrificial electrode of another metal (like Mg, Zn etc) which corrodes itself but saves the object.



#### Do you know?

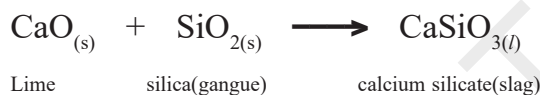
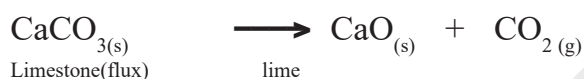
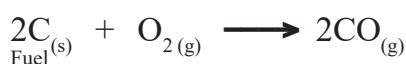
Alloying is a method of improving the properties of a metal. We can get desired properties by this method. For example, iron is the most widely used metal. But it is never used in its pure state. This is because pure iron is very soft and stretches easily when hot. But, if it is mixed with a small amount of carbon, it becomes hard and strong. When iron is mixed with nickel and chromium we get stainless steel which will not rust. Pure gold, known as 24 carat gold, is very soft. It is, therefore, not suitable for making jewellery. It is alloyed with either silver or copper to make it hard. Generally in India 22carat gold is used for making ornaments. It means that 22 parts of pure gold is alloyed with 2 parts of either silver or copper.

## A few important processes used in metallurgy

**Smelting:** Smelting is a pyrochemical (*pyre = heat*) process, in which the ore is mixed with flux and fuel and strongly heated. The heat is so strong that the ore is reduced to even metal as in the case of iron (Fe), and the metal is obtained in molten state. During smelting the impurities (gangue) in the ore react with flux to form slag which is removed. For haematite ( $\text{Fe}_2\text{O}_3$ ) ore, coke is used as fuel and lime stone ( $\text{CaCO}_3$ ) is used as flux. The smelting is carried out in a specially built furnace known as blast

furnace.

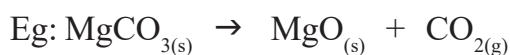
The reactions inside the furnace are:



**Roasting:** Roasting is a pyrochemical process in which the ore is heated in the presence of oxygen or air below its melting point. The products (like metal oxide from sulphide ore) obtained in the process also are in solid state. Generally reverberatory furnace is used for roasting.



**Calcination:** Calcination is a pyrochemical process in which the ore is heated in the absence of air. The ore gets generally decomposed in the process.



**Flux:** Flux is a substance added to the ore to remove the gangue from it by reacting with the gangue. If the impurity (gangue) is acidic substance like  $\text{SiO}_2$ , basic substance like CaO is used as flux and if the impurity is of basic

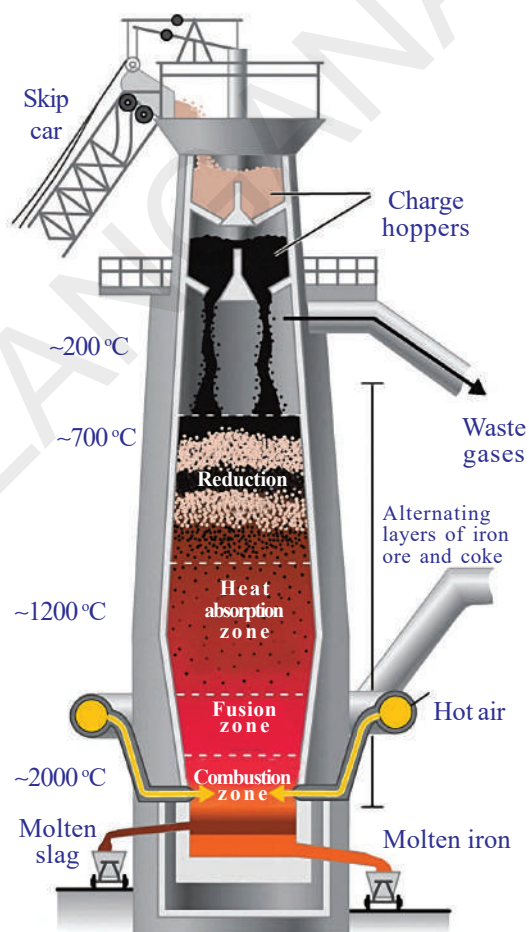
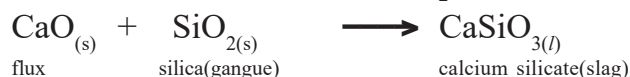


fig-6: Blast furnace

nature like FeO acidic flux like SiO<sub>2</sub> is added to the gangue.



- What is the role of furnace in metallurgy?
- How they bear large amounts of heat?
- Do all furnaces have same structure?

Let us see:

**Furnace:** Furnace is the one which is used to carry out pyrochemical processes in metallurgy. We have mainly three parts in a furnace known as Hearth, Chimney and fire box.

Hearth is the place inside the furnace where the ore is kept for heating purpose.

Chimney is the outlet through which flue (waste) gases go out of the furnace.

Fire box is the part of the furnace where the fuel is kept for burning.

In Blast furnace both fire box and hearth are combined in big chamber which accommodates both ore and fuel. Reverberatory furnace has both fire box and hearth separated, but the vapours (flame) obtained due to the burning of the fuel touch the ore in the hearth and heat it.

In furnaces like retort furnaces there is no direct contact between the hearth or fire box and even the flames do not touch the ore.

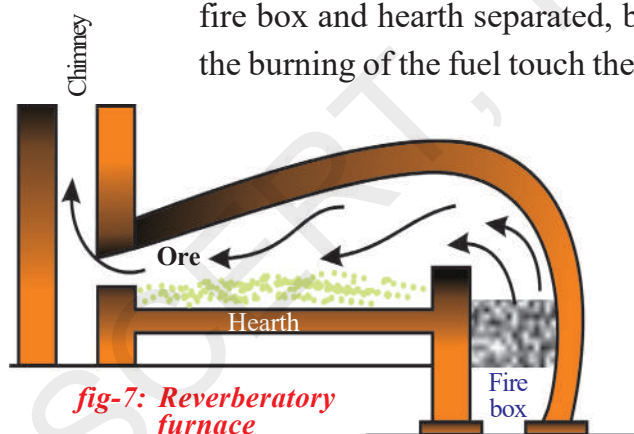


fig-7: Reverberatory furnace



### Key words

*Minerals, ores, froth flotation, Thermite process, distillation, poling, liquation, electrolytic refining, smelting, roasting, calcinations, blast furnace, reverberatory furnace.*



## What we have learnt

- A metallic compound occurring in the earth crust along with impurities is called mineral.
- A mineral from which a metal can be extracted economically and conveniently is called ore.
- The impurity present in the ore is called gangue..
- The substance added to the ore to remove gangue from it is called flux.
- The extraction of metal from its ore involves mainly three stages: Concentration, Extraction of crude metal, Refining of the metal.
- Physical methods adopted in dressing the ore are : hand picking, washing, froth flotation, Magnetic separation etc.
- The methods used for Extracting of Crude metal are Calcination, Roasting, Chemical reduction, Auto reduction, Displacement method, Electrolytic reduction .
- Calcination is a process of heating the ore strongly in the absence of air or oxygen.
- During calcinations, carbonate is converted to its oxide.
- Roasting is a process of heating the ore strongly in a free supply of air or oxygen.
- Calcination and Roasting are carried out in a reverberatory furnace



## Improve your learning

### Reflections on concepts

1. List three metals that are found in nature as Oxide ores.(AS<sub>1</sub>)
2. List three metals that are found in nature in un combined form. (AS<sub>1</sub>)
3. Write a note on dressing of ore in metallurgy? (AS<sub>1</sub>)
4. How do metals occur in nature? Give examples to any two types of minerals. (AS<sub>1</sub>)
5. When do we use magnetic separation method for concentration of an ore? Explain with an example. (AS<sub>1</sub>)
6. What is the difference between roasting and calcination? Give one example for each. (AS<sub>1</sub>)
7. Draw the diagram showing i) Froth floatation ii) Magnetic separation. (AS<sub>5</sub>)
8. Draw a neat diagram of riverboratory furnace and label it. (AS<sub>5</sub>)



### Application of concepts

1. Magnesium is an active metal, if it occurs as a chloride in nature, which method of reduction is suitable for its extraction? (AS<sub>2</sub>)
2. Mention two methods which produce very pure metals from impure metals. (AS<sub>1</sub>)
3. Which method do you suggest for extracting of high reactivity metals? (AS<sub>2</sub>)
4. Explain Thermite process and mention its applications in our daily life. (AS<sub>7</sub>)

5. Where do we use handpicking and washing methods in our daily life? Give examples. How do you correlate these examples with enrichment of ore? (AS<sub>7</sub>)

### Multiple choice questions

- The impurity present in the ore is called as [     ]  
a) Gangue                      b) flux                      c) Slag                      d) Mineral
- Which of the following is a carbonate ore? [     ]  
a) Magnesite                      b) Bauxite                      c) Gypsum                      d) Galena
- Which of the following is the correct formula of Gypsum [     ]  
a)  $\text{CuSO}_4 \cdot 2\text{H}_2\text{O}$                       b)  $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$                       c)  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$                       d)  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
- The oil used in the froth floatation process is [     ]  
a) kerosene oil                      b) pine oil                      c) coconut oil                      d) olive oil.
- Froth floatation is method used for the purification of \_\_\_\_\_ ore. [     ]  
a) sulphide                      b) oxide                      c) carbonate                      d) nitrate
- Galena is an ore of [     ]  
a) Zn                      b) Pb                      c) Hg                      d) Al
- The metal that occurs in the native form is [     ]  
a) Pb                      b) Au                      c) Fe                      d) Hg
- The most abundant metal in the earth's crust is [     ]  
a) Silver                      b) Aluminium                      c) zinc                      d) iron
- The reducing agent in thermite process is [     ]  
a) Al                      b) Mg                      c) Fe                      d) Si
- The purpose of smelting an ore is [     ]  
a) Oxidise                      b) Reduce                      c) Neutralise                      d) None of these

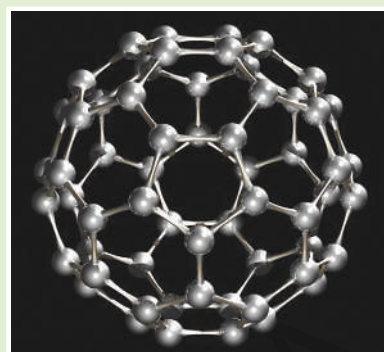
### Suggested Experiments

- Suggest an experiment to prove that the presence of air and water are essential for corrosion. Explain the procedure. (AS<sub>3</sub>)

### Suggested Projects

- Collect information about extraction of metals of low reactivity silver, platinum and gold and prepare a report. (AS<sub>4</sub>)





# Carbon and its Compounds

The food you eat, the clothes you wear, the cosmetics you use, the fuels you use to run automobiles are all the compounds of carbon.

Carbon was discovered in prehistory and it was known to the ancients. They used to manufacture charcoal by burning organic material.

**Carbon** is a non-metal. It belongs to the fourteenth group or IV A group in the modern periodic table. The elements of this group have four electrons in the valence shell.

Let us write the electronic configuration of Carbon ( ${}_6\text{C}$ ).

Atomic number of carbon is 6.

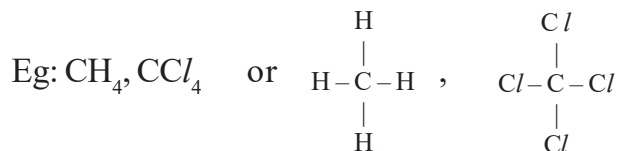
Electronic configuration of carbon (ground state)  ${}_6\text{C}$ :  $1s^2 2s^2 2p^2$ . To get the octet in its outer shell it has to gain four more electrons to form  $\text{C}^{4-}$ . The electronegativity of carbon is only 2.5 and its nucleus has only six protons. Therefore it would be difficult for a nucleus with six protons to hold ten electrons. Hence, carbon cannot form  $\text{C}^{4-}$  ions so easily.

- Can carbon get helium configuration by losing four electrons from the outer shell?

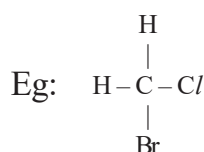
If carbon loses four electrons from the outer shell, it has to form  $\text{C}^{4+}$  ions. This requires huge amount of energy which is not available normally. Therefore  $\text{C}^{4+}$  formation also is a remote possibility. Carbon has to satisfy its tetravalency by sharing electrons with other atoms. It has to form four covalent bonds either with its own atoms or atoms of other elements.

The possibility of bonds formation by a carbon atom is as follows:

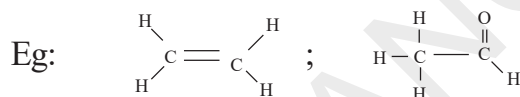
- a) i. Four single covalent bonds, with atoms of same element like hydrogen, Chlorine



- ii. Four single covalent bonds with atoms of different elements ;



- b) Carbon atoms may form one double bond and two single bonds



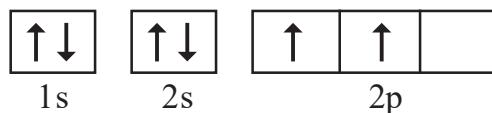
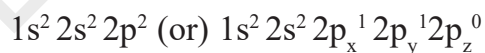
- c) Carbon atom may form one single bond and a triple bond

Eg:  $\text{H}-\text{C}\equiv\text{C}-\text{H}$  or  $\text{CH}_3-\text{C}\equiv\text{N}$  or carbon atoms may also form two double bonds as in  $\text{CH}_2 = \text{C} = \text{CH}_2$ .

- How do carbon atoms form bonds in so many different ways as mentioned above?
- Explain the four unpaired electrons in carbon atom through excited state.

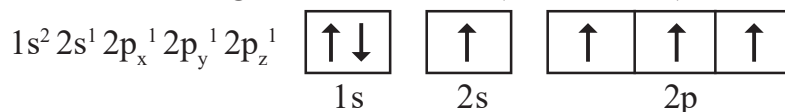
As per valence bond theory (see chapter-8, chemical bonding), the four unpaired electrons in a carbon atom are shown by suggesting excited state to carbon atom.

Electronic configuration of carbon (ground state):



*Carbon (ground state)*

Electronic configuration of carbon (excited state):



*Carbon (excited state)*

In excited state carbon atom gets its one of the '2s' electrons to say  $2p_z$ .

Each carbon atom has four unpaired electrons when excited and tends to form four covalent bonds.

- Where this energy to excite electron comes from?

We have to understand that free carbon atom would not be in excited state under normal conditions. When the carbon atom is ready to form bonds with other atoms, the energy required for excitation is taken up from bond energies, which are the liberated energies when bonds are formed between carbon atom and other atoms.

- In methane ( $\text{CH}_4$ ) molecule all four carbon – hydrogen bonds are identical and bond angle  $\text{H}\hat{\text{C}}\text{H}$  is  $109^\circ 28'$ . How can we explain this?

In the above discussion, we have found that in excited state, carbon atom has three unpaired electrons in p-orbitals and one electron in s-orbital. These four valence electrons are with different energies.

- How these energetically unequal valence electrons form four equivalent covalent bonds in methane molecule?

Let us see how?

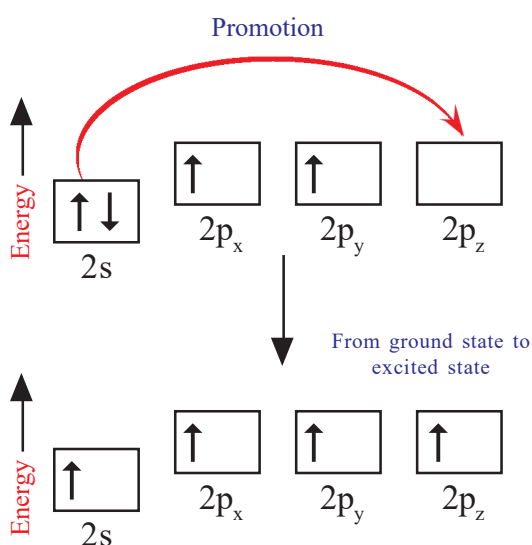
### Promotion of an electron

When bonds are formed, energy is released and the system becomes more stable. If carbon forms four bonds rather than two, still more energy is released and so the resulting molecule becomes even more stable.



**Linus Pauling** - The world's one of the greatest scientists and a great humanist. He was acknowledged as the most influential chemist.

He is the only person ever to receive two unshared Nobel Prizes — for Chemistry (1954) and for Peace (1962).



The energy difference between the 2s and 2p orbitals is very small. When carbon atom is ready to form bonds it gets a small amount of energy from bond energies and gets excited to promote an electron from the 2s to the empty 2p<sub>z</sub> to give four unpaired electrons.

We have got four unpaired electrons ready for bonding, but these electrons are in two different kinds of orbitals and their energies are different. We are not going to get four identical bonds unless these unpaired electrons are in four identical orbitals.

- How to explain the four orbitals of carbon containing unpaired electrons as energetically equal?

We can explain it by the phenomenon called hybridisation.

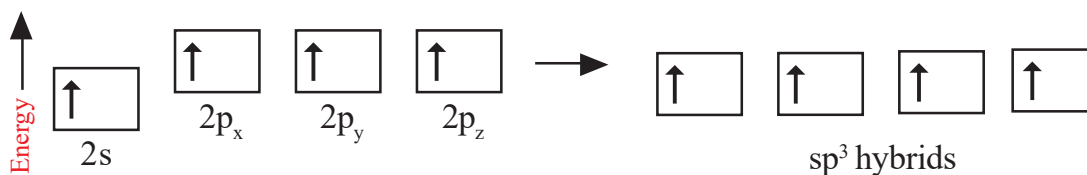
## Hybridisation

The concept of hybridisation was introduced by Linus Pauling (1931). The redistribution of orbitals of almost equal energy in individual atoms to give equal number of new orbitals with identical properties like energy and shape is called “hybridisation”. The newly formed orbitals are called as ‘hybrid orbitals.’

In the excited carbon atom its one s-orbital (2s) and three p-orbitals (2p<sub>x</sub>, 2p<sub>y</sub>, 2p<sub>z</sub>) intermix and reshuffle into four identical orbitals known as sp<sup>3</sup> orbitals. Thus, carbon atom undergoes sp<sup>3</sup> hybridisation.

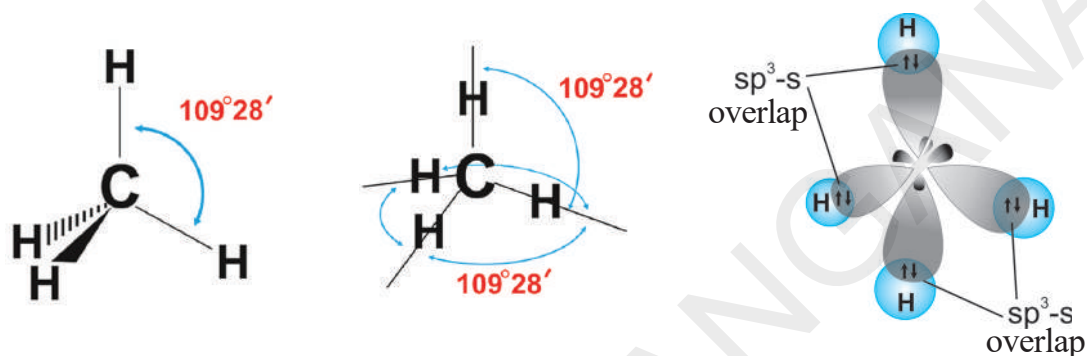
The four electrons enter into the new four identical hybrid orbitals known as sp<sup>3</sup> hybrid orbitals one each as per Hund’s rule. (because they are made from one ‘s-orbital’ and three ‘p-orbitals’ they are called sp<sup>3</sup> orbitals).

**NOTE:** Read “sp<sup>3</sup>” as “s p three”. or “yes pee three”



The hybridisation enables the carbon to have four identical sp<sup>3</sup> hybrid orbitals and these have one electron each. Since carbon has four unpaired

electrons, it is capable of forming bonds with four other atoms may be carbon or atoms of some other monovalent element. When carbon reacts with hydrogen, four hydrogen atoms allow their 's' orbitals containing one electron each to overlap the four  $sp^3$  orbitals of carbon atom which are oriented at an angle of  $109^\circ 28'$ . (Four orbitals of an atom in the outer shell orient along the four corners of a tetrahedron to have minimum repulsion between their electrons). The nucleus of the atom is at the centre of the tetrahedron. See figures below:

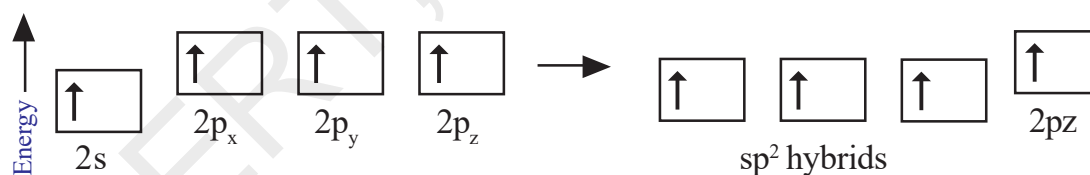


This leads to form four  $sp^3 - s$  sigma bonds between carbon atom and four hydrogen atoms. All these bonds are of equal energy.

### $sp^2$ hybridisation

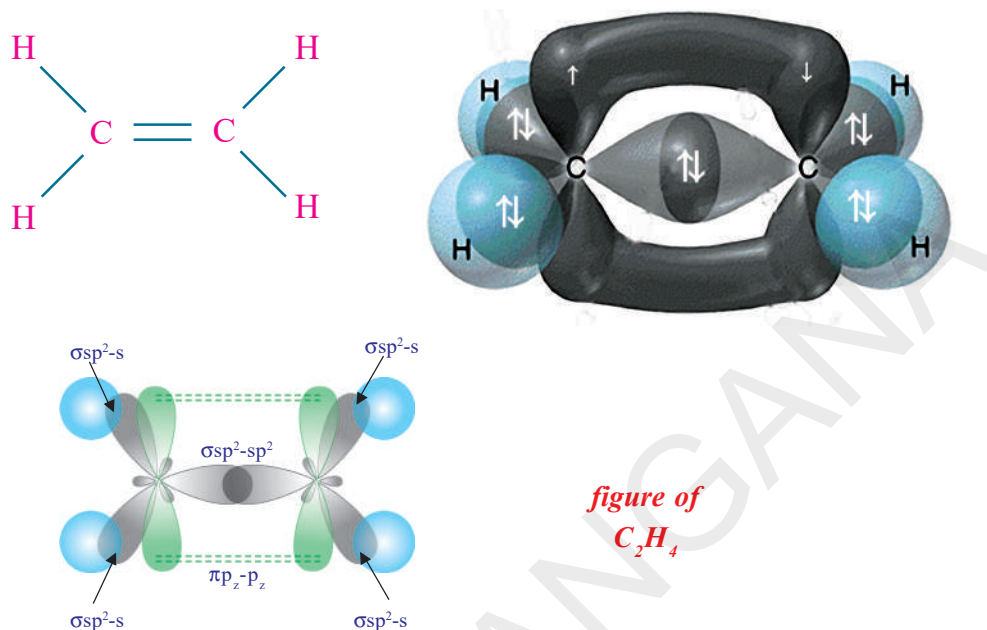
How do you explain the ability of C – atom to form two single covalent bonds and one double bond?

Consider *ethene / ethylene* ( $CH_2 = CH_2$ ) molecule as the example.



In the formation of  $CH_2=CH_2$  each carbon atom in its excited state *undergoes*  $sp^2$  hybridisation by intermixing one s-orbital (2s) and two p-orbitals (say  $2p_x$ ,  $2p_y$ ) and reshuffling to form three  $sp^2$  orbitals. Now each carbon atom is left with one 'p' orbital (say  $p_z$ ) unhybridised. The three  $sp^2$  orbitals having one electron each get separated around the nucleus of carbon atoms at an angle of  $120^\circ$ . When carbon is ready to form bonds one  $sp^2$  orbital of one carbon atom overlaps the  $sp^2$  orbital of the other carbon atom to form  $sp^2 - sp^2$  sigma ( $\sigma$ ) bond. The remaining two  $sp^2$  orbitals of each carbon atom get overlapped by 's' orbitals of two hydrogen atoms containing unpaired electrons. The unhybridised  $p_z$  orbitals on the two carbon atoms overlap laterally as shown in figure to form a  $\pi$  bond.

That means there exists a sigma ( $\sigma$ ) bond and a pi ( $\pi$ ) bond between two carbon atoms in ethene molecule. Hence, the molecule ethene ( $C_2H_4$ ) is



The common name for Ethene is Ethylene.

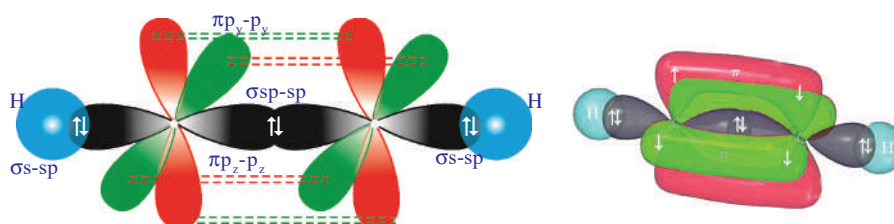
### sp hybridisation

Each carbon is only joining to two other atoms rather than four (as in methane or ethane) or three (as in ethene). Here the carbon atoms hybridise their outer orbitals before forming bonds, this time they only hybridise two of the orbitals.

They use the 's' orbital (2s) and one of the 2p orbitals, but leave the other 2p orbitals unchanged. The new hybrid orbitals formed are called **sp hybrid orbitals**, because they are made by an s-orbital and a p-orbital reorganizing themselves.

How do you explain the ability of carbon atom to form one single bond and one triple bond?

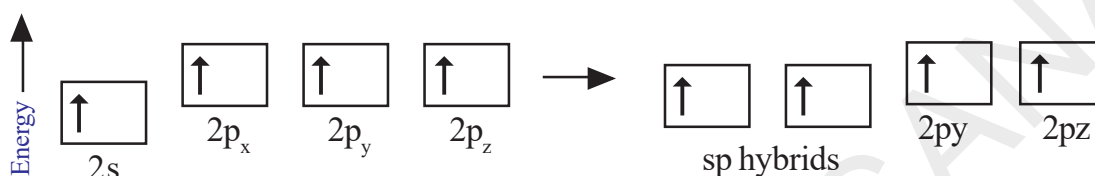
To know the ability of 'C' to form one single bond and one triple bond, let us consider *ethyne* (*acetylene* or  $C_2H_2$ ) molecule as our example.



*figure of  $C_2H_2$*

In acetylene molecule there exists a triple bond between two carbon atoms and the fourth valency of each carbon atom is satisfied by hydrogen atoms ( $\text{H}-\text{C} \equiv \text{C}-\text{H}$ ).

In  $\text{C}_2\text{H}_2$  molecule there are two carbon atoms and two hydrogen atoms. In excited state each carbon atom undergoes  $sp$ - hybridisation by mixing its one 's' orbital ( $2s$ ) and one 'p' orbital ( $2p_x$ ) and reshuffling to form two identical orbitals known as  $sp$ -orbitals. Each carbon atom has two unhybridised p-orbitals (say  $2p_y, 2p_z$ ).



One  $sp$ -orbital of a carbon overlaps the  $sp$ -orbital of other carbon to give  $sp$ - $sp$  sigma bond. The other  $sp$ -orbital of each carbon atom overlaps 's' orbital of a hydrogen atom to form a  $s$ - $sp$  sigma bond. The unhybridised 'p' orbitals of one carbon atom laterally overlap the unhybridised 'p' orbitals of other carbon atom to give two  $\pi$  bonds between two carbon atoms (say  $\pi_{p_y-p_y}, \pi_{p_z-p_z}$ , see figure). Thus ethyne molecule  $\text{H}-\text{C} \equiv \text{C}-\text{H}$  and there exists three  $\sigma$ -bonds and two  $\pi$ -bonds in the molecule.



### Think and discuss

Discuss the bond distance between the nuclei of carbon atoms that

form bonds and bond energies order of  $\text{H}-\text{C} \equiv \text{C}-\text{H}$ ,  $\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & / \\ & \text{C} = \text{C} \\ & / & \diagdown \\ \text{H} & & \text{H} \end{array}$  and  $\begin{array}{c} \text{H} & & \text{H} \\ | & & | \\ \text{H}-\text{C}- & - & \text{C}-\text{H} \\ | & & | \\ \text{H} & & \text{H} \end{array}$  Explain it.

What are bond angles  $\hat{\text{H}}\text{C}\text{H}$  in  $\text{CH}_4$ ,  $\text{C}_2\text{H}_4$  and  $\text{C}_2\text{H}_2$  molecules?

### Allotropes of Carbon

The property of an element to exist in two or more physical forms having more or less similar chemical properties but different physical properties is called *allotropy*. The different forms of the element are called *allotropes*. Allotropes form due to the difference in the arrangement of atoms in the molecules.

The allotropes of carbon are classified into two types. They are

- Amorphous forms
- Crystalline forms

## Amorphous forms

Different amorphous allotropes of carbon are: Coal; Coke; Wood Charcoal; Animal charcoal; Lamp black; Gas carbon; Petroleum coke; Sugar charcoal.

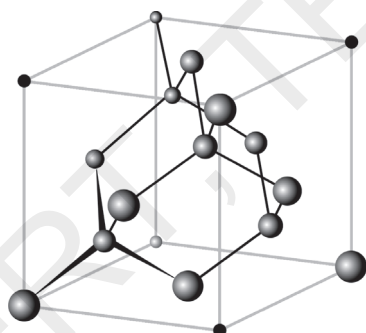
## Crystalline forms

Carbon atoms can arrange themselves into different hybridised chemical bonds. Therefore they exhibit different physical and chemical structures such as diamond and graphite. Carbon in solid phase can exist in three crystalline allotropic forms: **diamond, graphite and buckminsterfullerene.**

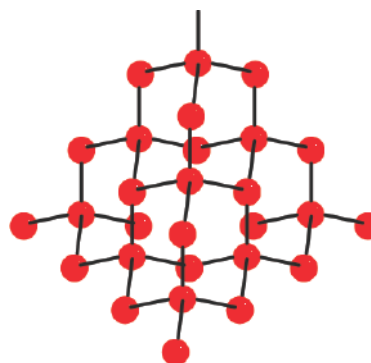
Diamond and graphite form covalent network structures whereas buckminsterfullerene has a molecular solid structure with discrete  $C_{60}$  molecules. As these crystalline allotropes differ in their structures, they possess different physical properties.

### Diamond

In diamond each carbon atom undergoes in its excited state  $sp^3$  hybridisation. Hence, each carbon atom has a tetrahedral environment. The three dimensional structure of diamond is as shown:



*Lattice structure of diamond*



*Diamond structure*

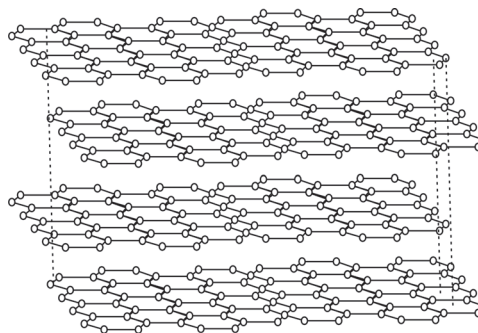
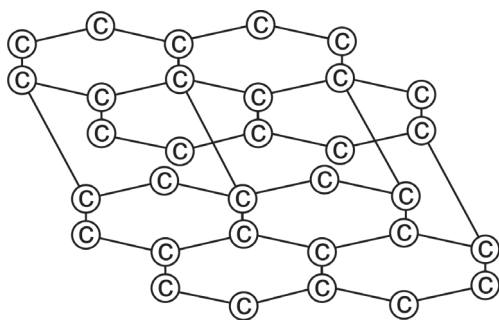
As C-C bonds are very strong any attempt to distort the diamond structure requires large amount of energy. Hence diamond is one of the hardest materials known.

### Graphite

Graphite forms a two dimensional layer structure with C-C bonds within the layers. There are relatively weak interactions between the layers.

In the layer structure, the carbon atoms are in a trigonal planar environment. This is consistent with each carbon atom in  $sp^2$  hybridisation. Interactions between the  $sp^2$  orbitals (overlaps) lead to the formation of C-C bonds. Each carbon atom is with one unhybridised 'p' orbital. The





*The arrangement of carbon atoms in graphite layers*

unhybridised 'p' orbitals interact to form a  $\pi$  system which is delocalised over the whole layer. The interactions known as London dispersion forces between the layers which are separated by a distance of 3.35 Å are weakened by the presence of water molecules so that it is easy to cleave graphite. For this reason graphite is used as lubricant and as the 'lead' in pencils.

- How do you understand the markings (writings) of a pencil on a paper?

When we write with a pencil, the interlayer attractions breakdown and leave graphite layers on the paper. Pencil marks are easy to remove from paper with an eraser because, the layers do not bind strongly to the paper. Graphite is a good conductor of electricity because of the delocalised  $\pi$  electron system.

### Buckminsterfullerene ( $C_{60}$ )

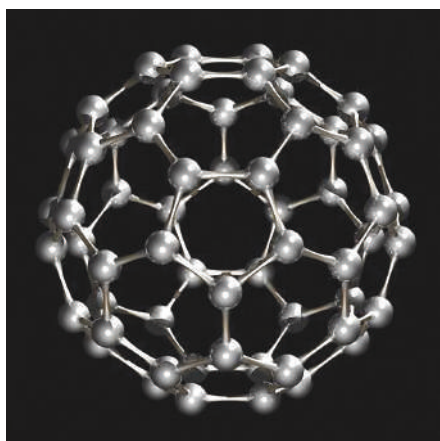
Buckminsterfullerenes are molecules of varying sizes that are composed entirely of carbon. The arrangement of these molecules leads to the form of a hollow sphere, ellipsoid, or tube depending upon their orientations. Fullerenes are formed when vaporized carbon condenses in an atmosphere of an inert gas.

#### **(?) Do you know?**

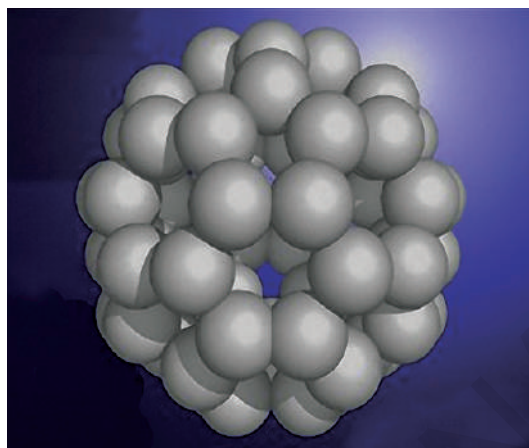
The *buckminsterfullerene*, or usually just *fullerene* for short, was discovered in 1985 by a team of scientists, Robert F. Curl, Harold W. Kroto and Richard E. Smalley from Rice University and the University of Sussex, three of whom were awarded the 1996 Nobel Prize in Chemistry. They are named so for the resemblance of their structure to the geodesic structures devised by the scientist and architect **Richard Buckminster "Bucky" Fuller**.

**Buckyballs:** Spherical fullerenes are also called *buckyballs*.

Buckminsterfullerene ( $C_{60}$ ) contains nearly spherical  $C_{60}$  molecules with the shape of a soccer ball.



**Buckminsterfullerene ( $C_{60}$ )**



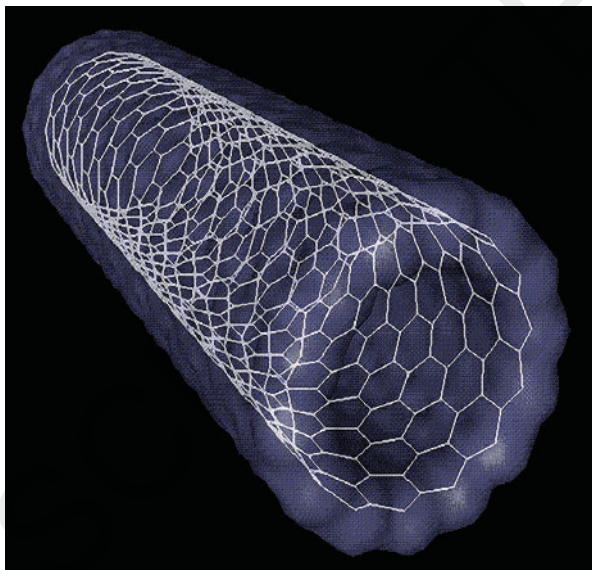
**3D structure of Buckminsterfullerene ( $C_{60}$ )**

Fullerene,  $C_{60}$  molecule contains 12 pentagonal and 20 hexagonal faces on its soccer ball shape, and each carbon atom has  $sp^2$  hybridized orbitals.

Fullerenes are under study for potential medicinal use - such as specific antibiotics to target resistant bacteria and even target certain cancer cells such as melanoma.

### Nanotubes

Nanotubes are another allotropic form of carbon discovered in 1991 by *Sumio Iijima*. Nano tubes consist of hexagonal arrays of covalently bonded carbon atoms, similar to the sheets in graphite. Unlike the flat graphite sheets, in nanotubes the sheets are rolled into cylinders. Due to this reason they are called nanotubes. Nanotubes like graphite, are electrical conductors and can be used as molecular wires. In integrated circuits nanotubes are used instead of copper to connect the components together. Scientists inserted biomolecules into nanotubes to inject them into a single cell.



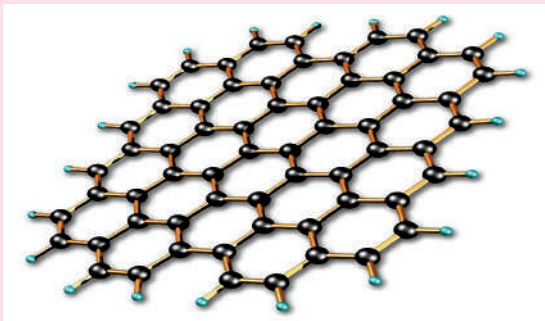
**Single-walled carbon nanotube or Buckytube**

### Versatile nature of carbon

By the eighteenth century scientists tried to explain the difference between the compounds in a broader way.

## (?) Do you know?

### Graphene - The new wonder material:



3D illustration showing a sheet of graphene



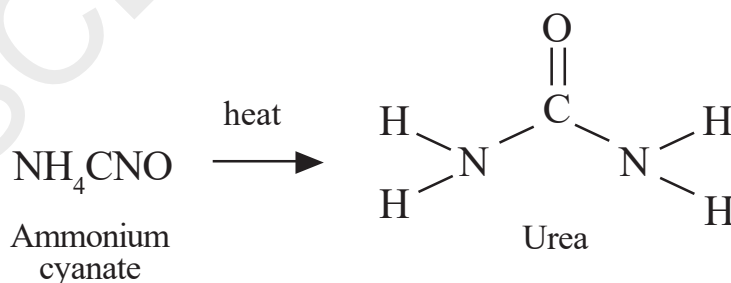
A piece of graphene aerogel - weighing only 0.16 milligrams per cubic centimeter - is placed on a flower.

As its name indicates, graphene is extracted from graphite, the material used in pencils. Like graphite, graphene is entirely composed of carbon atoms. For a thickness of 1mm graphite contains some 3 million layers of graphene. The carbons are perfectly distributed in a hexagonal honeycomb formation only in 0.3 nanometers thickness.

Graphene conducts electricity better than copper. It is 200 times stronger than steel but six times lighter. It is almost perfectly transparent to light.

*J. J. Berzelius* (1807) named the compounds that derived from living organism as organic compounds and those from non-living materials as inorganic compounds. He thought that organic compounds would be prepared in the living bodies through vital force, the essence of life. As this force is absent outside the living bodies, it was thought that the so called organic compounds could not be synthesized in the laboratories.

Surprisingly *F. Wohler* (1828) produced an organic compound **Urea** in the laboratory by heating an inorganic salt ammonium cyanate.



It inspired many other chemists and they were successful to prepare the so called organic compounds, methane, acetic acid etc., in the laboratory. This gave a death blow to the idea that organic compounds are derived from living organism. Chemists thought about a new definition for organic



### **Wöhler Friedrich (1800 – 1882)**

German chemist who was a student of Berzelius. In attempting to prepare ammonium cyanate from silver cyanide and ammonium chloride, he accidentally synthesized urea in 1828. This was the first organic synthesis, and shattered the vitalism theory.

Wöhler pursued the matter further and discovered that urea and ammonium cyanate had the same chemical formula, but very different chemical properties. This was an early discovery of isomerism, since urea has the formula  $\text{CO}(\text{NH}_2)_2$  and ammonium cyanate has the formula  $\text{NH}_4\text{CNO}$ .

compounds. After observing the structures and elements of organic compounds, they defined organic compounds as compounds of carbon. Therefore, organic chemistry is totally allotted to carbon compounds.

- Allotting completely one special branch in chemistry to compounds of only one element. Is it justified when there are so many elements and their compounds but not with any special branches?

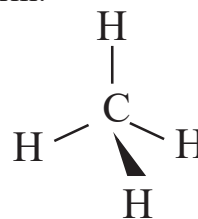
We understand that all molecules that make life possible – carbohydrates, proteins, nucleic acids, lipids, hormones, and vitamins contain carbon. The chemical reactions that take place in living systems are of carbon compounds. Food that we get from nature, various medicines, cotton, silk and fuels like natural gas and petroleum almost all of them are carbon compounds. Synthetic fabrics, plastics, synthetic rubber are also compounds of carbon. Hence, carbon is a special element with the largest number of compounds.

### **Catenation**

Another peculiar behaviour of carbon is its ability to form longest chains with its own atoms. If any element forms bonds between its own atoms to give big molecules we call that property as catenation property. Carbon has the ability to form longest chains containing millions of carbon atoms in molecules like some proteins. Sulphur, phosphorus and some other non metals have this property but to a very less extent.

You have understood that carbon can form:

- a) Four single covalent bonds ,



- b) A double bond and two single covalent bonds ( $>C=C$ )
- c) A single covalent bond and a triple bond ( $-C\equiv C$ ), or two double bonds ( $C=C=C$ ) with its own atoms or atoms of other elements – to satisfy its tetravalency.

This ability of carbon to form bonds in so many ways made it as versatile element in nature. Hence, carbon's ability 1) to form largest number of compounds 2) to show catenation 3) to form various types of bonds made it the versatile element.

## Hydrocarbons

- What are hydrocarbons?

The compounds containing only carbon and hydrogen in their molecules are called **hydrocarbons**.

Hydrocarbons are classified into two categories known as *open chain hydrocarbons* and *closed chain hydrocarbons*. Open chain hydrocarbons are also called *aliphatic hydrocarbons* or *acyclic hydrocarbons*.

### Open and closed chain hydrocarbons

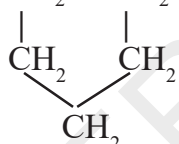
Let us observe the following structural formulae of different hydrocarbons.

1)  $CH_3-CH_2-CH_2-CH_2-CH_3$  n-pentane, a straight chain compound

2)  $CH_3-CH-CH_2-CH_3$ . Iso pentane, a branched chain compound

$$\begin{array}{c} | \\ CH_3 \end{array}$$

3)  $CH_2 - CH_2$  cyclo pentane, a cyclic compound *or* a ring compound



- Do all the above compounds have equal number of C and H atoms?

In the first example you will notice that all carbons are linked to one another resulting a linear structure, where as in the second example four carbons are linked in linear way and the fifth carbon is linked to the parent chain resulting a branch. In the third example we find that carbon chain is closed to form a ring. So, it is a closed chain hydrocarbon or ring hydrocarbon.

All hydrocarbons (both Aliphatic and cyclic hydrocarbons) are again classified as Alkanes, Alkenes and Alkynes:

- 1) Hydrocarbons containing only single bonds between carbon atoms are called *Alkanes*. ( $C-C$ )
- 2) Hydrocarbons containing atleast one double bond between carbon

atoms are called *Alkenes*. ( $C=C$ )

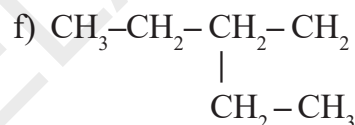
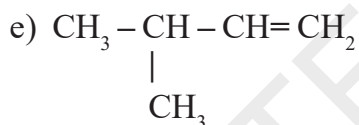
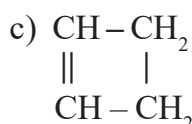
- 3) Hydrocarbons containing at least one triple bond between carbon atoms are called *Alkynes*. ( $C \equiv C$ )

### Saturated and unsaturated hydrocarbons

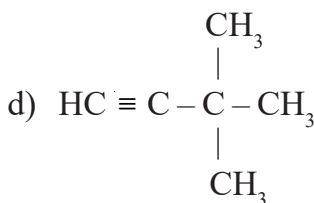
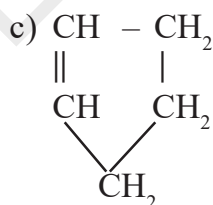
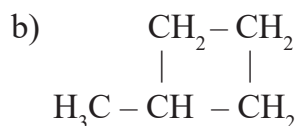
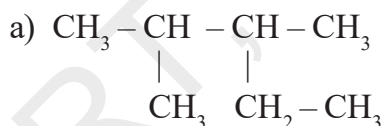
The hydrocarbons containing only C–C single bonds are known as *saturated hydrocarbons*. All alkanes are saturated hydrocarbons. The hydrocarbons that contain at least one double bond ( $C=C$ ) or contain at least one triple bond ( $C \equiv C$ ) between the two carbon atoms are called *unsaturated hydrocarbons*. Alkenes and Alkynes are the examples for unsaturated hydrocarbons.

Straight chain, branched chain and closed chain hydro carbon compounds may be saturated or unsaturated. See the following examples.

- 1) Which of the following compounds are unsaturated?



- 2) Identify the compounds in the following, as branched chain and closed chain compounds.



### Binding of carbon with other elements

We have understood that the compounds of carbon and hydrogen are called hydrocarbons.

- Can carbon form bonds with the atoms of other elements?

Practical observations reveal that carbon forms compounds not only with atoms of hydrogen but also with atoms of other elements like oxygen,

nitrogen, sulphur, phosphorus, halogens etc.

Let us see the compounds of carbon with other elements.

## Functional groups in carbon compounds

The characteristic properties of an organic compound depend mainly on an atom or group of atoms in its molecule known as the *functional group*.

Organic compounds are classified by the type of functional group they contain. Functional groups are responsible for the behavior of the organic compounds. Compounds containing the same functional group undergo similar types of reactions.

### Carbon compounds with C, H, X.

- Compounds containing C, H, X where 'X' represents halogens (Cl, Br, I atoms).

**Eg:**  $\text{CH}_3\text{Cl}$ ,  $\text{CH}_3\text{-CH}_2\text{-Br}$ ,  $\text{CH}_2\text{Cl-CH}_2\text{I}$ ,  $\text{CH}_3\text{-CHCl}_2$

These are known as *halogen derivatives* of hydrocarbons or halo hydrocarbons.

### Carbon compounds with C, H, O.

#### Halo Hydrocarbons

- Compounds containing C, H, O are of different types:

#### Alcohols

If a hydrogen atom of  $\text{H}_2\text{O}$  molecule is replaced by 'R' we get alcohols R-OH.

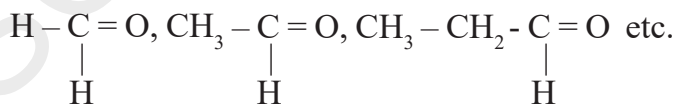
The hydrocarbons that contain -OH group are called alcohols. Observe the following examples:

$\text{CH}_3\text{OH}$ ,  $\text{CH}_3\text{CH}_2\text{OH}$ ,  $\text{CH}_3\text{-CHOH-CH}_3$  etc.

General formula of alcohols is **R-OH** where 'R' is *alkyl* group,  $\text{C}_n\text{H}_{2n+1}$ .

#### Aldehydes

The hydrocarbons with functional group -CHO are called aldehydes. Observe the following examples:



Formaldehyde

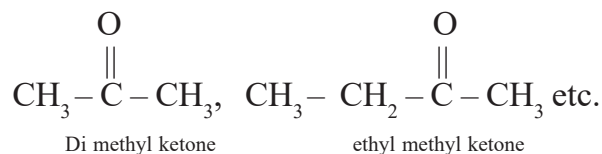
Acetaldehyde

Propionaldehyde

General formula of aldehydes is **R-CHO**, where **R** = alkyl group or hydrogen and -CHO is functional group.

## Ketones

The hydrocarbons with  $\begin{matrix} \text{C} \\ > \\ \text{C} \end{matrix} \text{C}=\text{O}$  functional group are called ketones.



$\begin{matrix} \text{C} \\ > \\ \text{C} \end{matrix} \text{C}=\text{O}$  group is known as *Ketone group* (common system)

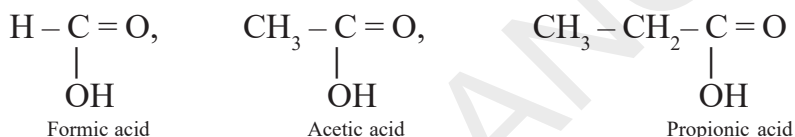
General formula of Ketones is  $\begin{matrix} \text{R} \\ > \\ \text{R}' \end{matrix} \text{C}=\text{O}$

**R** and **R<sup>1</sup>** are alkyl groups which may be same or different.

## Carboxylic acids

The general molecular formula of carboxylic acid is **R – COOH**,

where **R** is an alkyl group or **H** atom.

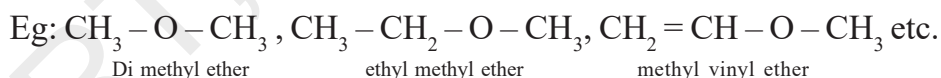


$\begin{matrix} - \text{C} = \text{O} \\ | \\ \text{OH} \end{matrix}$  group is called the *carboxyl group*.



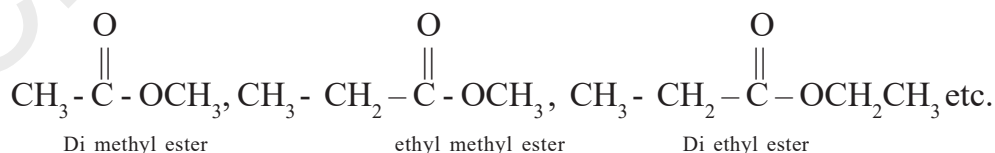
## Ethers

Ethers are carbon compounds related to  $\text{H}_2\text{O}$  in such a way that both hydrogen atoms are replaced by two alkyl groups which may be same or different.



## Esters

These compounds are derivatives of carboxylic acids. If the hydrogen atom of **-COOH** gets replaced by 'R', the alkyl group esters are obtained.

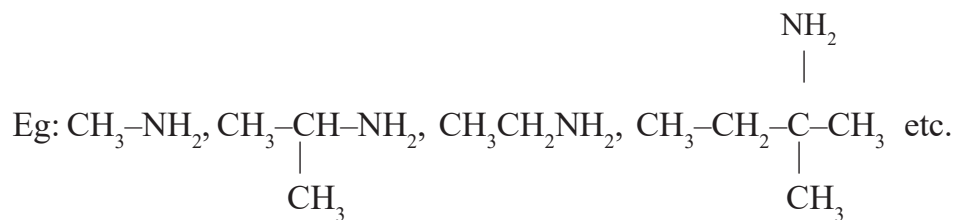


## Compounds containing C, H, N

### Amines

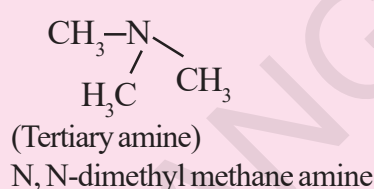
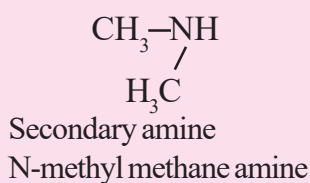
If hydrogen atom is replaced from  $\text{NH}_3$  by an alkyl group are called *Amines*. **-NH<sub>2</sub>** group is called *amine group*.





### **(?) Do you know?**

We may compare amines to  $\text{NH}_3$  as we have done  $\text{ROH}$  and  $\text{R-O-R}'$  to  $\text{H}_2\text{O}$ . If one Hydrogen Atom is replaced from  $\text{NH}_3$  by an alkyl group we get *primary amines*. If two hydrogen atoms of  $\text{NH}_3$  are replaced by two alkyl groups (same or different) we get *secondary amines* and if all the three hydrogen atoms are replaced by the same or different alkyl groups we get *tertiary amines*.



### **Isomerism**

Observe the following two structures:



- How about their structures? Are they same?
- How many carbon and hydrogen atoms are there in (a) and (b) structures?
- Write the condensed molecular formulae for (a) and (b). Do they have same molecular formulae?

The first one is called *butane* (or) in the common system it is known as *n-butane*.

The second one is called *2-methyl propane* or *iso-butane* in the common system.

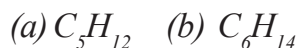
We find both of these compounds in nature. They have different properties due to the difference in their structures. Compounds of this type which have the same molecular formula but different properties are called *isomers*.

The phenomenon of possessing same molecular formula but different properties by the compounds is known as *isomerism*. The compounds that exhibit isomerism are called *isomers*.

(*iso* = same; *meros* = part, i.e., they have same molecular formula)

In the above example isomerism is due to the difference in the structures. Therefore, it is called the *structural isomerism*.

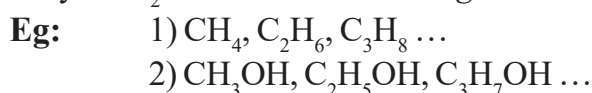
Try to draw different structures for the following carbon compounds and name the isomers of each (Take the help of your teacher)



### Homologous series

Till now we have classified Organic compounds on the basis of carbon chains and functional groups. There is another classification based on Homologous series.

The series of carbon compounds in which two successive compounds differ by  $-CH_2$  unit is called *homologous series*.



If you observe above series of compounds, you will notice that each compound in the series differs by  $-CH_2$  unit by its successive compound.

Homologous series of organic compounds have following characteristic features.

- 1) They have one general formula.  
**Eg:** alkanes ( $C_nH_{2n+2}$ ); alkynes ( $C_nH_{2n-2}$ ); alcohols ( $C_nH_{2n+1}OH$ ) etc.
- 2) Successive compounds in the series possess a difference of ( $-CH_2$ ) unit.
- 3) They possess similar chemical properties due to the same functional group  
**Eg:** alcohols, aldehydes and carboxylic acids have functional groups  $C-OH$ ,  $C-CHO$  and  $C-COOH$  respectively.
- 4) They show a regular gradation in their physical properties (see the table-1).

For example: we may take alkanes, alkenes, alkynes, alcohols, aldehydes, and carboxylic acids etc. as homologous series. The individual members of a homologous series are called *homologs*.

Observe the following tables 1, 2 and 3. They represent three different homologous series.

**Table-1: Homologous series of Alkanes**

Alkane	Molecular formula	Structure	No. of carbons	Boiling Point ( $^{\circ}C$ )	Melting Point ( $^{\circ}C$ )	Density (gml $^{-1}$ at $20^{\circ}C$ )
Methane	$CH_4$	H- $CH_2$ -H	1	-164	-183	0.55
Ethane	$C_2H_6$	H-( $CH_2$ ) $_2$ -H	2	-89	-183	0.51
Propane	$C_3H_8$	H-( $CH_2$ ) $_3$ -H	3	-42	-189	0.50
Butane	$C_4H_{10}$	H-( $CH_2$ ) $_4$ -H	4	0	-138	0.58
Pentane	$C_5H_{12}$	H-( $CH_2$ ) $_5$ -H	5	36	-136	0.63

The general formula of this homologous series Alkanes is  $C_nH_{2n+2}$ , where  $n = 1, 2, 3, \dots$

**Table-2: Homologous series of Alkenes**

Alkene	No. of Carbons	Structure	Formula
Ethene	2	$\text{CH}_2=\text{CH}_2$	$\text{C}_2\text{H}_4$
Propene	3	$\text{CH}_3-\text{CH}=\text{CH}_2$	$\text{C}_3\text{H}_6$
Butene	4	$\text{CH}_3-\text{CH}_2-\text{CH}=\text{CH}_2$	$\text{C}_4\text{H}_8$
Pentene	5	$\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}=\text{CH}_2$	$\text{C}_5\text{H}_{10}$

Alkenes have general molecular formula  $\text{C}_n\text{H}_{2n}$ , where 'n' is 2, 3, 4, ...

**Table-3: Homologous series of Alkynes**

Alkyne	No. of Carbons	Structure	Formula
Ethyne	2	$\text{HC}\equiv\text{CH}$	$\text{C}_2\text{H}_2$
Propyne	3	$\text{CH}_3-\text{C}\equiv\text{CH}$	$\text{C}_3\text{H}_4$
Butyne	4	$\text{CH}_3-\text{H}_2\text{C}-\text{C}\equiv\text{CH}$	$\text{C}_4\text{H}_6$
Pentyne	5	$\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{C}\equiv\text{CH}$	$\text{C}_5\text{H}_8$

Alkynes have general molecular formula  $\text{C}_n\text{H}_{2n-2}$ , where 'n' is 2, 3, 4, ...

### Nomenclature of organic compounds

We have millions of organic compounds. As number of organic compound is very big it is difficult to remember their names individually. To overcome this problem they have to be properly named. For this, the International Union of Pure and Applied Chemistry (IUPAC) had been formed, and one of its responsibilities is to name the organic and inorganic compounds in a systematic order. The basic idea behind the systematic nomenclature is that there should be only one name for the given structure throughout the world and also there should be only one structure for the given name.

The IUPAC name of an organic compound consists of three parts : 1) Word root 2) Prefix 3) Suffix.

**1) Word Root :** The number of carbon atoms present in the molecules or principle chain is called word root.

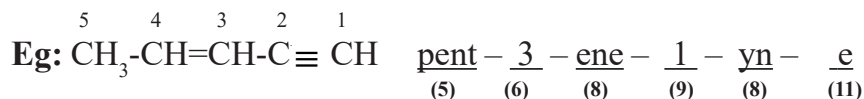
$\text{C}_1$ - Meth;	$\text{C}_2$ - eth;	$\text{C}_3$ - prop;	$\text{C}_4$ - but ;	$\text{C}_5$ -pent; $\text{C}_6$ - hex;
$\text{C}_7$ - hept;	$\text{C}_8$ -oct;	$\text{C}_9$ -non;	$\text{C}_{10}$ - dec	and so on.

**2) Prefix :** The substituents in the molecule are shown as the prefix. Prefix again has several parts known as *primary prefix secondary prefix, numerical prefix* and *number prefix*.

**Primary prefix :** It is useful only for cyclic compounds (Cyclo). If the compounds are not cyclic, this part of the name is absent.



(6) and (7) tell about the positions and repetitions of the multiple bonds in the structures of the molecule of the compound. These are related to the primary suffix (8) that tells about the unsaturation.



(9) and (10) tell about the positions and repetitions of the functional group or principal functional group (11) in a poly functional compound. It gives the information which carbon represents it or to which carbon that functional group is attached and how many times it is repeated. If it comes only once we need not write *mono* i.e., if no numerical prefix is present it is understood that the functional group is not repeated. Similarly, in the names of aliphatic compounds word root (5), primary suffix (8) and secondary suffix (11) are definitely present and all others may or may not be present. If there are more than one similar functional groups, 'e' letter of primary suffix may not be replaced.



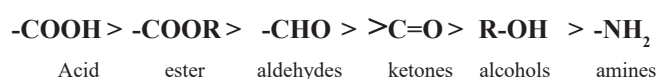
**Punctuation:** Numbers are separated by *comma* (,) and numbers & designations by *hyphen*(-)

If you find more than one substituent in the structure you have to follow alphabetical order while naming them. For this numerical prefixes should not be considered. Substituents: X (halo), R (alkyl), -OR (alkoxy), -NO<sub>2</sub> (nitro), NO (nitroso) etc.

If you find more than one functional group in the structure you select the principal functional group and write it as secondary suffix. All other functional groups become substituents.

A decreasing order of priority for choosing and naming a principal characteristic group. This should be written as secondary suffix.

(C) indicates that "C" of functional group is included in the main carbon chain.



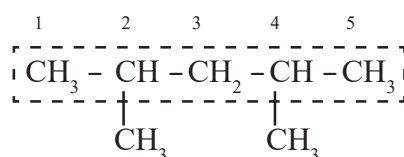
### Suffixes and prefixes for some important characteristic functional groups:

Class	Formula	Prefix	Suffix
Acid halides	-COX (Where X is halogen atom)	halocarbonyl	carbonyl halide
	-(C)O-X		oyl halide
Alcohols	-OH	hydroxy	ol
Aldehydes	-CHO	formyl	carbaldehyde
Amides	-CONH <sub>2</sub>	carbamoyl	carboxamide
Amines	-NH <sub>2</sub>	amino	amine
Carboxylic acids	-COOH	carboxy	carboxylic acid
	-(C)OOH		oic acid
Ethers	-OR	(R)alcoxy	
Esters	-COOR	oxycarbonyl	(R)...carboxylate
	(C)OOR	R - oxycarbonyl	(R)...oate
Ketones	-C = O	oxo	-one
Nitriles	-CN	cyano	-carbonytrile
	-(C)N		Nitrile

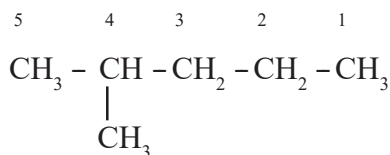
### Numbering carbon atoms

- 1) We can number carbon atoms from left to right or from right to left so that sum of the numbers indicating the positions of substituents and functional groups should be minimum possible.
- 2) The functional group carbon should be given the lowest number even if it does not obey Rule (1).
- 3) The carbon atoms of the chain terminating functional group say -CHO, or -COOH groups should be given always number '1' even if it does not obey Rules (1) & (2).

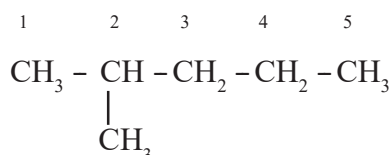
**Longest Chain rule :** Select the longest continuous chain of Carbon atom which is known as parent chain or principle chain. All the other Carbon atoms constitute in the chain are branched chains or side chains.



**Lowest Number rule :** The Carbon compound which contains only one substituent number the Carbon atom in such a way that the carbon atom carrying the substituent get the lowest number.

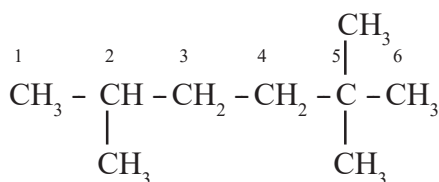


(Incorrect method)

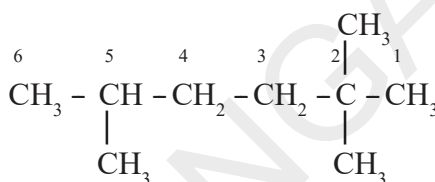


(Correct method)

**Lowest Sum rule :** If there are two or more substituents in the carbon compounds the parent chain is numbered from the end which gives the lowest sum of more substituent carbon.



(2+5+5 = 12 Incorrect method)

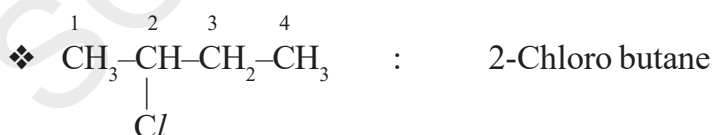


(2+2+5 = 9 Correct method)

**Alphabetical Order :** When two or more different groups are present, such groups are arranged in alphabetical order.

## Activity 1

Observe the names of the following compounds. Divide the given name as per the notations given above and identify the parts in the name through the numbers given above from (1) to (11) and write them in your note book. Take the help of your teacher



- $$\begin{array}{cccc} 4 & 3 & 2 & 1 \\ \text{CH}_3 & -\text{CH} & =\text{C} & =\text{CH}_2 \end{array} \quad :$$
 Buta 1, 2- diene
- $$\begin{array}{cccc} 4 & 3 & 2 & 1 \\ \text{CH}_3 & -\text{CH}_2 & -\text{CH}_2 & -\text{CH}_2-\text{OH} \end{array} \quad :$$
 Butan – 1 – ol
- $$\begin{array}{cccc} 4 & 3 & 2 & 1 \\ \text{CH}_3 & -\text{CH}_2 & -\text{CH}_2 & -\text{CHO} \end{array} \quad :$$
 Butanal
- $$\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{COOH} \quad :$$
 Butanoic acid
- $$\begin{array}{ccc} \text{CH}_2 & -\text{CH}_2 & \\ | & | & \\ \text{CH}_2 & -\text{CH}_2 & \end{array} \quad :$$
 Cyclo butane
- $$\begin{array}{ccc} \text{Br} & \text{Br} & \\ | & | & \\ \text{CH} & -\text{CH} & \\ | & | & \\ \text{CH}_2 & -\text{CH}_2 & \end{array} \quad :$$
 1,2 – di bromo cyclo butane
- $$\begin{array}{c} \text{CH}_3-\text{C}-\text{CH}_2-\text{CH}_2-\text{CH}_3 \\ || \\ \text{O} \end{array} \quad :$$
 Penta n – 2 - one
- $$\begin{array}{ccc} \text{CH}_2 & -\text{CH} & -\text{CHO} \\ | & | & \\ \text{Cl} & \text{Cl} & \end{array} \quad :$$
 2, 3 – di chloro propanal
- solution 
$$:$$
 2,3 - di chloro prop an al  
 (1) (2) (3) (5) (8) (11)

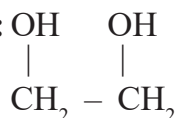
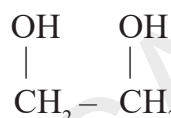
**Let us observe some more examples.**

NOTE: (C) designates a carbon atom included in the name of the parent hydride and does not belong to a group designated by a suffix or a prefix.

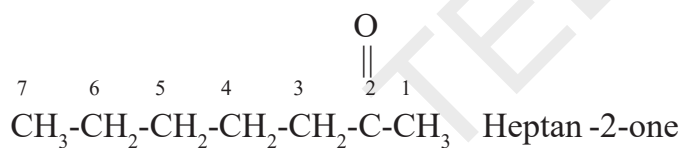
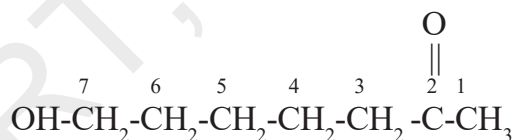
**Example:**  $\text{CH}_3-\text{CH}_2-\text{CHO}$  propanal - (C) of CHO included in the name of the main chain.

$$\begin{array}{c} \text{CH}_3-\text{CH}-\text{COOH} \\ | \\ \text{CHO} \end{array}$$
 2- formyl propanoic acid - 'C' of CHO not included in the name of main (parent) chain.



**Example-1:**  $\text{CH}_3\text{CH}_2\text{OH}$ Principal functional group :  $-\text{OH}$  (-ol)Parent hydride :  $\text{CH}_3 - \text{CH}_3$ Parent hydride + one Principal functional group  $\rightarrow \text{CH}_3\text{CH}_2\text{OH}$ Name of the compound  $\rightarrow$  Eth an ol  
(5) (8) (11)**Example-2:**Parent hydride + two Principal functional groups  $\rightarrow$ Name of the compound  $\rightarrow$  eth ane - 1,2 - di ol  
(5) (8) (9) (10) (11)**Example-3:**  $\text{CH}_3 - \overset{\text{O}}{\parallel}{\text{C}} - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{OH}$ Principal functional group  $>(\text{C}) = \text{O}$  -oneParent hydride  $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$  Heptane

Parent hydride + Principal functional group

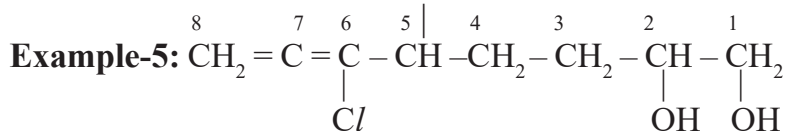
Substituent  $-\text{OH} \rightarrow$  HydroxyName of the compound 7 - hydroxy hept an - 2 - one  
(1) (3) (5) (8) (9) (11)**Note:** In the solution the principal functional group  $>\text{C}=\text{O}$  (Keto) group is given more priority than to  $-\text{OH}$  (alcohol).**Example-4:**  $\text{CH}_2 = \text{CH} - \text{CH}_2 - \underset{\text{OH}}{\text{CH}} - \text{CH}_3$ Parent hydride  $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$  PentanePrincipal functional group  $-\text{OH}$  -ol

Principal hydride + Principal functions Pentan - 2 - ol

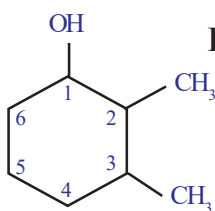
Subtractive modification (-2H)

-en

Name of the compound:  $\frac{\text{Pent}}{(5)} - \frac{4}{(6)} - \frac{\text{en}}{(8)} - \frac{2}{(9)} - \frac{\text{ol}}{(11)}$   
 $\text{Cl}$



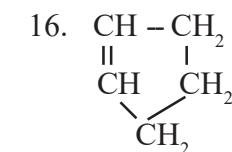
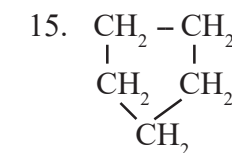
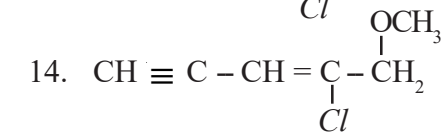
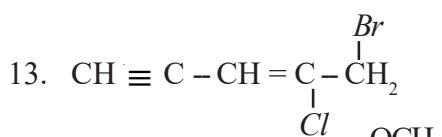
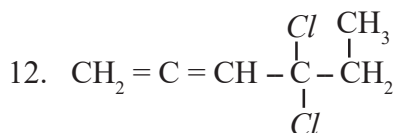
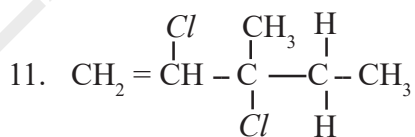
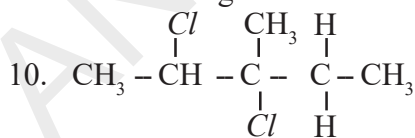
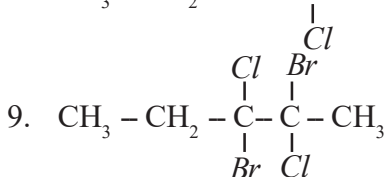
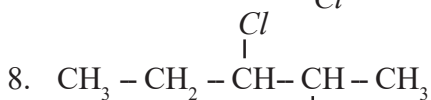
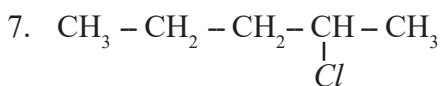
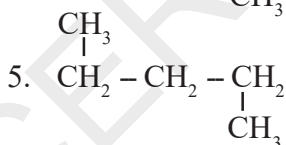
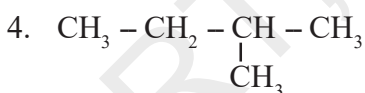
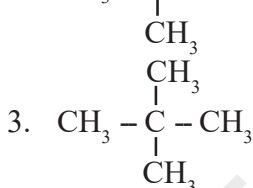
$\frac{5,6}{(1)} - \frac{\text{di}}{(2)} \frac{\text{chloro}}{(3)} - \frac{\text{octa}}{(5)} - \frac{6,7}{(6)} - \frac{\text{di}}{(7)} \frac{\text{en}}{(8)} - \frac{1,2}{(9)} - \frac{\text{di}}{(10)} \frac{\text{ol}}{(11)}$

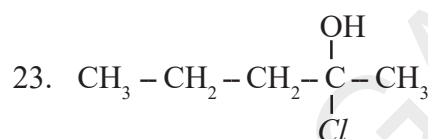
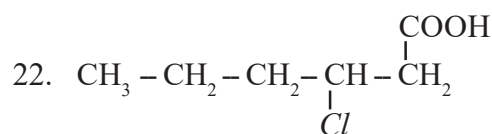
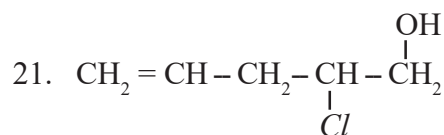
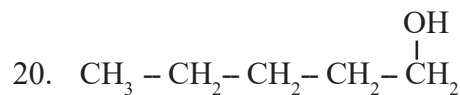
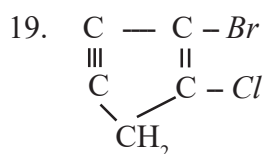
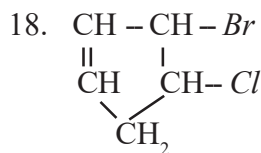
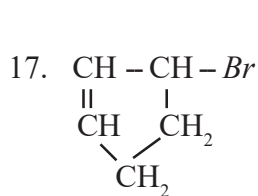


**Example-6:**

$\frac{2,3}{(1)} - \frac{\text{di}}{(2)} \frac{\text{methyl}}{(3)} - \frac{\text{cyclo}}{(4)} \frac{\text{hex}}{(5)} \frac{\text{an}}{(8)} - \frac{1}{(9)} - \frac{\text{ol}}{(11)}$

Write the names of the organic compounds which have the following structure.





### How to draw structure of a compound

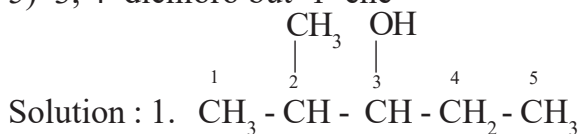
- Can we write the structure of a compound if the name of the compound is given?

Yes, we can write the structures from the name of the compound as follows:

- 1) From the word root in the name write the carbon atoms in the main chain
- 2) Select counting of carbon atoms in the appropriate manner from left to right or right to left as for the name given.
- 3) Attach the substituents to respective carbon atoms as per their numbers and numerical designations.
- 4) Find the functional group if any from the name of the compound see that it is correctly arranged in the structure.
- 5) Keeping in view that the tetravalency of each carbon atom has to be satisfied use hydrogen atoms in the required number and complete the structure..

### Examples:

- 1) 2-methyl pentan-3-ol
- 2) 2-bromo-3-ethyl penta-1, 4-diene
- 3) 3-bromo-2-chloro-5-oxohexanoic acid
- 4) 3-amino-2-bromo hexan-1-ol
- 5) 3, 4-dichloro but-1-ene



## Chemical properties of carbon compounds

Though we have millions of organic compounds, the reactions they undergo are limited. Some important reactions among them are discussed here.

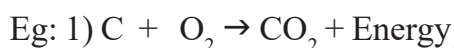
They are:

- 1) Combustion
- 2) Oxidation reactions
- 3) Addition reactions
- 4) Substitution reactions

### 1. Combustion reactions

Carbon, and its compounds burn in presence of oxygen or air to give  $\text{CO}_2$ , heat and light.

The process of burning of carbon or carbon compound in excess of oxygen to give heat and light is called the *combustion reaction*. In the reactions carbon is in its maximum oxidation state of  $4^+$  in the product.



Generally, saturated hydrocarbons burn with a clear light blue flame, whereas unsaturated hydrocarbons burn with yellow flame with soot (carbon). If air is not sufficiently available during combustion, even saturated hydrocarbons give sooty flame. When Coal, Petroleum etc., burn in air, they give oxides of sulphur and nitrogen in addition to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  which pollute the environment. When Coal or Charcoal is burnt sometimes they just glow red without flame. This is because to get a flame gaseous fuels should burn.

Most of the aromatic compounds burn with sooty flame.

- Why do sometimes cooking vessels get blackened on a gas or kerosene stove?

Because of the inlets of air getting closed, the fuel gases donot completely undergo combustion. Hence, it forms a sooty carbon form which gets coated over the vessels.

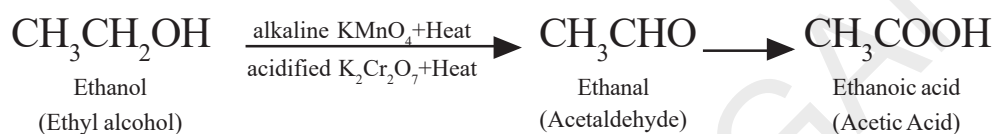
A combustion reaction is generally defined as any reaction that sustains a flame. It usually involves burning with oxygen, though some exceptions are there, combustion reaction is always exothermic, that is energy is liberated during combustion reaction.

## 2. Oxidation reactions

Though combustion is generally oxidation reaction, all oxidation reactions are not combustion reactions. Oxidation reactions may be carried out using oxidizing agents. *Oxidizing agents* or *Oxidants* are substances that oxidize other substances. They themselves undergo *reduction*.

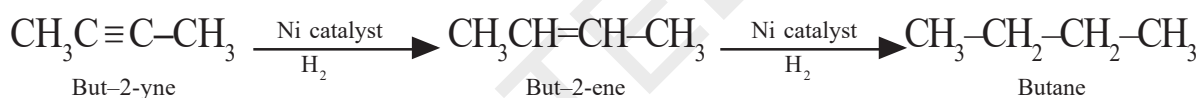
Eg: Alkaline Potassium permanganate or Acidified Potassium dichromate in solutions act as oxidizing agents and supplies oxygen to convert alcohols into carboxylic acids.

Ethyl alcohol undergoes oxidation to form the product *Acetaldehyde* and finally *Acetic acid*. (see following equation)



## 3. Addition reactions

Unsaturated organic compounds that contain multiple bonds (=, ≡ bonds) like alkenes and alkynes undergo addition reactions to become saturated. During the reactions addition of the reagent takes place at the double bonded or triple bonded carbon atoms.



In the above reactions 'Ni' acts as 'catalyst.'

- **Do you know what a 'catalyst' is?**

A catalyst is a substance which increases the rate of a given reaction without itself finally undergoing any chemical change.

These reactions are commonly used in the hydrogenation of vegetable oils using nickel as catalyst. Vegetable oils generally have long unsaturated carbon chains, while animal fats have saturated carbon chains.



### Think and discuss

- Why we are advised not to use animal fats for cooking?
- Which oil is recommended for cooking? Why?

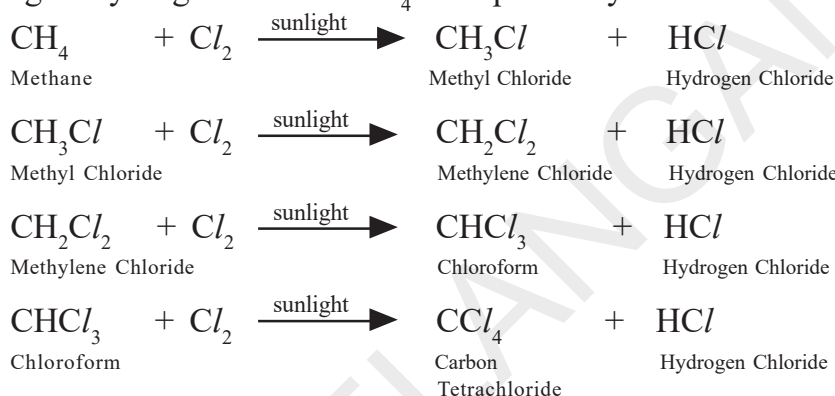
Fats and oils are both of fatty acids. Oils are generally liquids at room temperature due to unsaturated fatty acids but fats are solids due to saturated fatty acids.

## 4. Substitution reactions

A reaction in which an atom or a group of atoms in a given compound is replaced by other atom or group of atoms is called a substitution reaction.

Alkanes, the saturated hydrocarbons are chemically least reactive. Therefore they are also called *paraffins* (*parum* = little; *affins* = affinity, i.e., no affinity towards chemical changes). However they undergo some chemical changes under suitable conditions which are substitution reactions.

For example, methane (CH<sub>4</sub>) reacts with chlorine in the presence of sunlight. Hydrogen atoms of CH<sub>4</sub> are replaced by chlorine atoms.

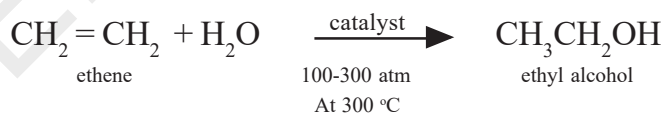


### Some important carbon compounds

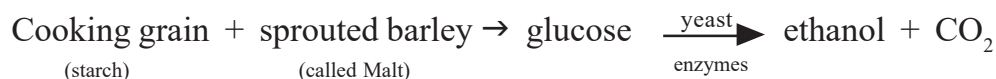
Many carbon compounds are invaluable to us. But here we study, the properties of Ethanol (Ethyl alcohol) and Ethanoic acid (Acetic acid) which are two very important carbon compounds.

#### Ethanol (Ethyl alcohol)

**Preparation:** Ethanol is prepared on large scale from ethene by the addition of water vapour to it in the presence of catalysts like P<sub>2</sub>O<sub>5</sub>, Tungsten oxide at high pressure and temperature.



Grains such as corn, wheat, barley are common sources for ethanol. Therefore, it is also called grain alcohol.



The process of conversion of starches and sugars to C<sub>2</sub>H<sub>5</sub>OH is called *fermentation process*.

#### Properties

Ethanol is a colourless liquid with characteristic sweet odour. Pure ethanol boils at 78.3 °C. Pure ethanol is called *absolute (100 %) alcohol*.

Denatured alcohol is ethanol that contains impurities that make it undrinkable. The impurities are methanol, methyl isobutyl ketone, aviation gasoline etc. It is toxic and 200 ml of it is a fatal dose to an adult. Solution of about 10% ethanol in gasoline (gasohol) is a good motor fuel.

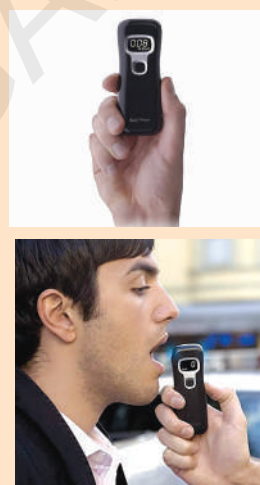
Ethanol is commonly called alcohol and is active ingredient of all alcoholic drinks. Consumption of small quantity of dilute ethanol causes drunkenness. In addition, as it is a good solvent it is also used in medicines such as tincture iodine, cough syrups and many tonics

- Do you know how the police detect whether suspected drivers have consumed alcohol or not?

The police officer asks the suspect to blow air into a plastic bag through a mouth piece of the detecting instrument which contains crystals of potassium-di-chromate ( $K_2Cr_2O_7$ ). As  $K_2Cr_2O_7$  is a good oxidizing agent, it oxidizes any ethanol in the driver's breath to ethanol and ethanoic acid.

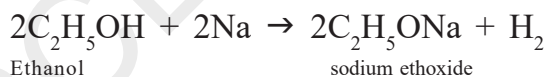
Orange  $Cr_2O_7^{2-}$  changes to bluish green  $Cr^{3+}$  during the process of the oxidation of alcohol. The length of the tube that turned into green is the measure of the quantity of alcohol that had been drunk. Now a days police are using even an electronic instrument containing small fuel cell that measures the electrical signal produced when ethanol in the breath is oxidized.

The police even use the IR Spectra to detect the bonds C – OH and C – H of  $CH_3 - CH_2OH$ .

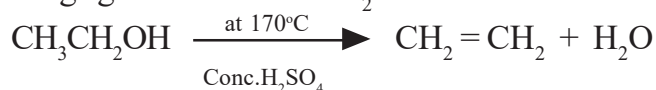


## Chemical properties

As ethanol is similar to water molecule ( $H_2O$ ) with  $C_2H_5$  group in place of hydrogen, it reacts with metallic sodium to liberate hydrogen and form *sodium ethoxide*.



**Action of conc.  $H_2SO_4$ :** Ethanol reacts with conc.  $H_2SO_4$  at about  $170^\circ C$  (443 K) to give ethene. It is a dehydration reaction.  $H_2SO_4$  is a dehydrating agent and removes  $H_2O$ .



## Ethanoic acid (Acetic acid or $CH_3COOH$ )

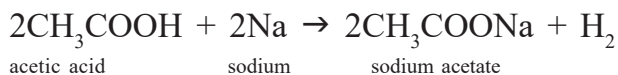
Ethanoic acid is a colourless liquid with characteristic unpleasant odour. It is soluble in water and more acidic than  $H_2O$  or ethanol, but less acidic than mineral acids.

Ethanoic acid is commonly called as acetic acid. 5-8% solution of acetic acid in water is called vinegar and is used widely as a preservative in pickles.

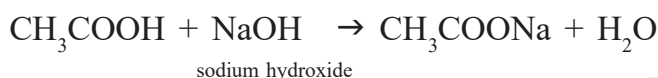
### Chemical Reactions

**Acidity:** (Reaction with metals and alkalis)

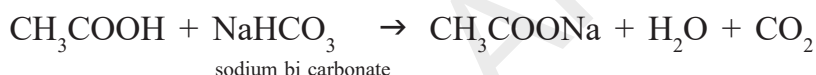
1) Ethanoic acid reacts with active metals like Na to liberate hydrogen. This reaction is similar to that of ethanol.



2) Ethanoic acid reacts with NaOH to form sodium acetate and water.



3) Ethanoic acid reacts with sodium carbonate and sodium hydrogen carbonate which are weaker bases and liberates CO<sub>2</sub>.

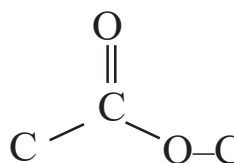


The strength of acids may be expressed in terms of their *pKa* values.

### 4) Esterification Reactions

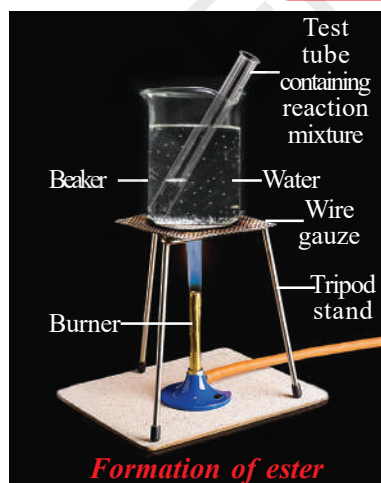
- What are esters?

Esters contain the functional group



The general formula is R – COO – R'. R and R' are *alkyl groups* or *phenyl groups*.

### Activity 2



Take 1 ml of ethanol (absolute alcohol) and 1ml of glacial acetic acid along with a few drops of concentrated sulphuric acid in a test tube.

Warm it in a water-bath or a beaker containing water for at least five minutes as shown in Fig.

Pour the warm contents into a beaker containing 20-50 ml of water and observe the odour of the resulting mixture.

- What do you notice?

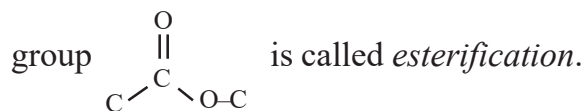
You will notice that the resulting mixture is a sweet odoured substance. This substance is nothing but ethyl acetate, an ester. The reaction in activity – 2 is called

*esterification reaction.*



## Esterification

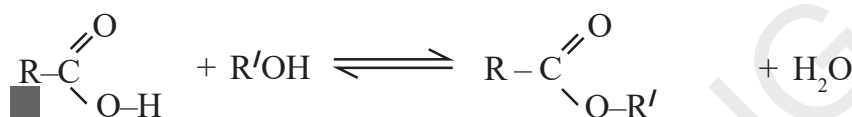
The reaction between carboxylic acid and an alcohol in the presence of conc.  $\text{H}_2\text{SO}_4$  to form a sweet odoured substance, **ester** with the functional



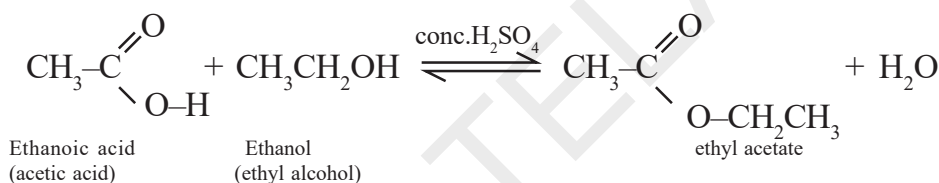
The esterification reaction is slow and reversible.

The equation for the reaction between an acid  $\text{RCOOH}$  and an alcohol  $\text{R}'\text{OH}$

(where  $\text{R}$  and  $\text{R}'$  can be the same or different) is:



So, for example, if you want to prepare ethyl ethanoate or ethyl acetate from ethanoic acid and ethanol, the equation would be:



## Soaps – Saponification and Micelles

Do you know what ‘soap’ is?

Soap is a sodium or potassium salt of a higher fatty acid like palmitic acid ( $\text{C}_{15}\text{H}_{31}\text{COOH}$ ), stearic acid ( $\text{C}_{17}\text{H}_{35}\text{COOH}$ ), oleic acid ( $\text{C}_{17}\text{H}_{33}\text{COOH}$ ) etc. The formula of a soap in general is  $\text{RCOONa}$  or  $\text{RCOOK}$ , where  $\text{R} = \text{C}_{15}\text{H}_{31}$ ;  $\text{C}_{17}\text{H}_{35}$  etc.

Fats are esters of higher fatty acids and the trihydroxy alcohol known as **glycerol**.

When fats are treated with sodium hydroxide, sodium salts the fatty acids and glycerol is formed. The sodium salts of these higher fatty acids being soaps the reaction is the soap formation reaction which is generally called as ‘saponification reaction’.

### Saponification reaction

Alkaline hydrolysis of tri esters of higher fatty acids producing soaps is called *saponification*.

Soaps are good cleansing agents. Do you know how they do this?

For understanding this you should know about a 'true solution' and a *colloidal solution*.

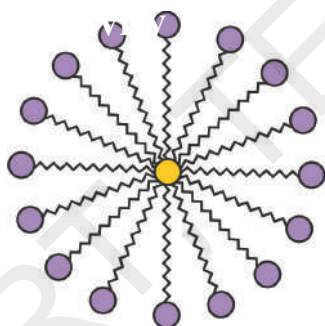
- What is a true solution?

A true solution is that in which the solute particles dispersed in the solvent are less than  $1\text{nm}$  in diameter. A colloidal solution contains the solute known as 'dispersed phase' with its particles with diameters greater than  $1\text{nm}$  but lesser than  $1000\text{nm}$  in the solvent known as '*dispersion medium*'.

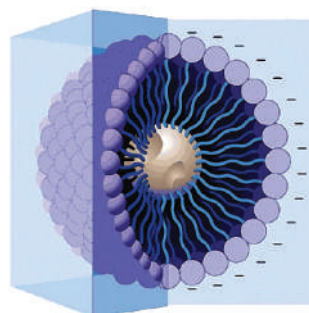
Soap is an electrolyte. When soap is put in water in very small amount it gives low concentrated solutions. It gives true solution but, above a particular concentration known as *critical micelle concentration* (CMC), the soap particles get aggregated and these aggregated particles are of colloidal size known as *micelles* or *associated colloids*.

### Micelle

A spherical aggregate of soap molecules in water is called *micelle*. When soap is dissolved in water, it forms a colloidal suspension in which the soap molecules cluster together to form spherical micelles.



*Micelle*



*3D structure of a micelle*

### Activity 3

#### Formation of micelle

Take about 10 ml of water each in two test tubes.

Add a drop of oil (cooking oil) to both the test tubes and label them as A and B.

Add a few drops of soap solution to test tube B.

Now shake both the test tubes vigorously for the same period of time.

What is that you find in them?

Can you see the oil and water layers separately in both the test tubes

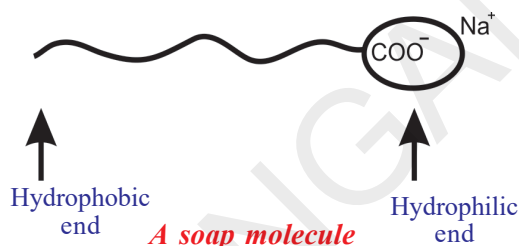
immediately after

- You stop shaking them?
- Leave the test tubes undisturbed for sometime and observe. Does the oil layer separate out?
- In which test tube does this happen first? Give your observations.

### Cleansing action of soap

Suppose that we put dirty cloth in the soap solution. Dirt is mainly greasy matter. The soap molecules are arranged radially with hydrocarbon ends directed inwards into the greasy matter and ionic part directed outwards into water.

When a dirty cloth is inserted in the solution then the hydrocarbon part sticks to the dirt or oil. With a little agitation the dirt particles get entrapped by the soap micelles and get dispersed in water due to which the soap water gets dirty and the cloth gets cleaned.



- What is the action of soap particles on the greasy cloth?

We know that soaps and detergents make oil and dirt present on the cloth come out into water, thereby making the cloth clean.

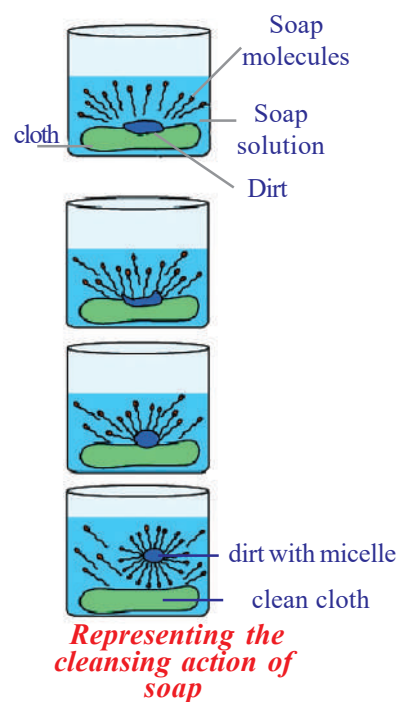
Soap has one polar end (the end with  $\text{-}\overset{\text{O}}{\parallel}{\text{C}}\text{-O}$  carboxy) and one non-polar end (the end with hydrocarbon chain) as shown in the figure.

The polar end is hydrophilic in nature and this end is attracted towards water.

The non-polar end is hydrophobic, in nature and it is attracted towards grease or oil on the cloth, but not attracted towards water.

When soap is dissolved in water, its hydrophobic ends attach themselves to dirt and remove it from the cloth, as shown sequentially in the figure that follows.

- The hydrophobic end of the soap molecules move towards the dirt or grease particle.
- The hydrophobic ends attached to the dirt particle and try to pull out.
- The molecules of soap surround the dirt particle



at the centre of the cluster and form a spherical structure called micelle.

These micelles remain suspended in water like particles in a colloidal solution.

The various micelles present in water do not come together to form a precipitate as each micelle repels the other because of the ion-ion repulsion.

Thus, the dust particles remain trapped in micelles (which remain suspended) and are easily rinsed away with water. Hence, soap micelles remove dirt by dissolving it in water.



### Key words

*Hybridisation, allotropy, diamond, graphite, buckminsterfullerene, nanotubes, catenation, tetravalency, hydrocarbons, alkanes, alkenes, alkynes, saturated hydrocarbons, unsaturated hydrocarbons, functional group, isomerism, homologous series, nomenclature, combustion, oxidation, addition reaction, substitution reaction, ethanol, ethanoic acid, ester, esterification, saponification, micelle.*



### What we have learnt

- Carbon forms a large variety of compounds. Its tetravalency and the property of catenation and ability to form four single bonds, a double bond and two single bonds, a triple bond and a single bond or two double bonds makes carbon versatile and brings one special branch in chemistry for carbon compounds.
- Hydrocarbons are the compounds of carbon and hydrogen.
- Hydrocarbons are of two types – saturated hydrocarbons (alkanes) and unsaturated hydrocarbons (alkenes and alkynes).
- Carbon forms covalent bonds with its own atoms and atoms of other elements such as hydrogen, oxygen, sulphur, nitrogen and chlorine.
- The functional groups such as alcohols, aldehydes, ketones and carboxylic acids bestow characteristic properties to the carbon compounds that contain them. Even  $C=C$ ,  $C\equiv C$ , give characteristic properties.
- A group / series of hydrocarbons having same general formula, with two successive compounds possessing difference of  $-CH_2$  and with similar structures and similar properties (i.e., same functional group) are called a homologous series.

- Carbon chains may be in the form of straight chains, branched chains or rings.
- Carbon compounds with identical molecular formula but different structures are called structural isomers.
- Saturated hydrocarbons on combustion give carbon dioxide and water with the liberation of heat.
- Unsaturated hydrocarbons undergo addition reactions while saturated hydrocarbons undergo substitution reactions.
- Ethanol and Ethanoic acid (glacial acetic acid) are carbon compounds of importance in our daily life.



### Improve your learning



#### Reflections on concepts

1. What are the general molecular formulae of alkanes, alkenes and alkynes. (AS<sub>1</sub>)
2. Name the product other than water formed on burning of ethanol in air. (AS<sub>1</sub>)
3. Name the simplest ketone and write its molecular formula. (AS<sub>1</sub>)
4. Name the compound formed by heating ethanol at 443 K with excess of conc. H<sub>2</sub>SO<sub>4</sub>. (AS<sub>1</sub>)
5. Name the product obtained when ethanol is oxidized by either chromic anhydride or alkaline potassium permanganate. (AS<sub>1</sub>)
6. Write the homologous series of carbon compounds after CH<sub>3</sub>OHCH<sub>2</sub>CH<sub>3</sub> and write the IUPAC name. (AS<sub>1</sub>)
7. Why does carbon form compounds mainly by covalent bonding? (AS<sub>1</sub>)
8. Explain how sodium ethoxide is obtained from ethanol? Give chemical equations. (AS<sub>1</sub>)
9. Explain the cleansing action of soap. (AS<sub>1</sub>)
10. Distinguish between esterification and saponification reactions of organic compounds. (AS<sub>1</sub>)
11. What happens when a small piece of sodium is dropped into ethanol? (AS<sub>2</sub>)
12. Draw the electronic dot structure of ethane molecule (C<sub>2</sub>H<sub>6</sub>). (AS<sub>5</sub>)

#### Application of concepts

1. Explain with the help of a chemical equation, how an addition reaction is used in vegetable ghee industry. (AS<sub>1</sub>)
2. a) Write the various possible structural formulae of a compound having molecular formula C<sub>3</sub>H<sub>6</sub>O? (AS<sub>1</sub>)  
b) Give the IUPAC names of the above compounds write their structures. (AS<sub>1</sub>)  
c) What is the similarity in these compounds? (AS<sub>1</sub>)
3. Allotropy is a property shown by which class of substances : elements, compounds or mixtures? Explain allotropy with suitable examples. (AS<sub>1</sub>)

4. Two carbon compounds A and B have molecular formulae  $C_3H_8$  and  $C_3H_6$  respectively. Which one of the two is most likely to undergo addition reactions? Justify your answer. (AS<sub>2</sub>)
5. 1ml of glacial acetic acid and 1ml of ethanol are mixed together in a test tube. Few drops of concentrated sulphuric acid is added to the mixture and warmed in a water bath for 5 min. Answer the following:
- Name the resultant compound formed. (AS<sub>2</sub>)
  - Represent the above change by a chemical equation. (AS<sub>1</sub>)
  - What name is given to such a reactions? (AS<sub>1</sub>)
  - What are the special characteristics of the compound formed? (AS<sub>1</sub>)

### Multiple choice questions

- Which of the following solution of acetic acid in water can be used as preservative? [      ]
  - 5-10%
  - 10-15%
  - 15-20%
  - 100%
- The suffix used for naming an aldehyde is [      ]
  - ol
  - al
  - one
  - ene
- Acetic acid, when dissolved in water, it dissociates into ions reversibly because it is a: [      ]
  - Weak acid
  - strong acid
  - weak base
  - strong base
- Which one of the following hydrocarbons can show isomerism? [      ]
  - $C_2H_4$
  - $C_2H_6$
  - $C_3H_8$
  - $C_4H_{10}$
- Combustion of hydrocarbon is generally accompanied by the evolution of
  - Heat
  - Light
  - both heat and light
  - Electric current.
- 2ml of ethanoic acid was taken in each of the three test tubes A, B and C and 2ml, 4ml and 8ml of water was added to them, respectively. A clear solution is obtained in: [      ]
  - Test tube A only
  - Test tubes A & B only.
  - Test tubes B and C only
  - All the test tubes.
- If 2 ml of acetic acid was added slowly in drops to 5ml of water then we will notice [      ]
  - The acid forms a separate layer on the top of water.
  - Water forms a separate layer on the top of the acid.
  - Formation of a clear and homogenous solution.
  - Formation of a pink and clear solution.

8. A few drops of ethanoic acid were added to solid sodium carbonate. The possible results of the reactions are: [      ]
- a) A hissing sound was evolved                      b) Brown fumes evolved.  
 c) Brisk effervescence occurred.                      d) A pungent smelling gas evolved.
9. When acetic acid reacts with ethyl alcohol, we add conc.  $H_2SO_4$ , which acts as.....and the process is called..... [      ]
- a) Oxidizing agent, saponification                      b) Dehydrating agent, esterification  
 c) Reducing agent, Esterification                      d) Acid & esterification

### Suggested Experiments

- Suggest a test to find the hardness of water and explain the procedure. (AS<sub>3</sub>)
- Suggest a chemical test to distinguish between ethanol and ethanoic acid and explain the procedure. (AS<sub>3</sub>)
- An organic compound 'X' with a molecular formula  $C_2H_6O$  undergoes oxidation with alkaline  $KMnO_4$  and forms the compound 'Y' that has molecular formula  $C_2H_4O_2$ . (AS<sub>3</sub>)
  - Identify 'X' and 'Y'
  - Write your observation regarding the product when the compound 'X' is made to react with compound 'Y' which is used as a preservative for pickles.

### Suggestive Projects

- Prepare models of methane, ethane, ethene and ethyne molecules using clay balls and match sticks. (AS<sub>4</sub>)
- Collect information about artificial ripening of fruits by ethylene. (AS<sub>4</sub>)
- How do you condemn the use of alcohol as a social practice. (AS<sub>7</sub>)



## ANNEXURE

### What is $pK_a$ ?

$pK_a$  is the negative value of logarithm of dissociation constant of an acid.

$pK_a$  is a measure of how much an acid dissociates in a solution.

$$pK_a = -\log_{10} K_a$$

The lower the  $pK_a$  value, the stronger is the acid.

$pK_a$  values are related to their dissociation in aqueous solutions. Note that  $pK_a$  of 1.0M HCl is zero but  $pK_a$  of  $CH_3COOH$  is 4.76.  $pK_a$  values are useful to tell about acid strength. Strong acids have  $pK_a < 1$ , acids with  $pK_a$  between 1 and 5 are moderately strong and weak acids have  $pK_a$  between 5 and 15. The weakest acids have  $pK_a > 15$ . Note that  $pK_a$  values less than zero are not generally given as they are of no use to give in terms of  $pK_a$ . They may be directly given in terms of  $K_a$ .



## ANNEXURE

# Nomenclature of carbon compounds

Prefix		Primary prefix		Word root		Suffix				
Secondary prefix		Primary prefix		Continuous longest carbon chain		Primary suffix		Secondary suffix		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Number ↓ 1, 2, 3....	Numerical Designation → Di → Tri → Tetra	Halide/ Alkyle/ secondary functional group <b>Halide</b> → Floro → Chloro → Bromo → Iodo <b>- R-Alkyl</b> → - CH <sub>3</sub> - Methyl → - C <sub>2</sub> H <sub>5</sub> - Ethyl → - C <sub>3</sub> H <sub>7</sub> - Propyl....	(Only for cyclic compounds) → <b>Cyclo</b>	<b>Number of Carbons</b> ↑ 1 - Meth ↑ 2 - Eth ↑ 3 - Prop ↑ 4 - But ↑ 5 - Pent ↑ 6 - Hex ↑ 7 - Hept ↑ 8 - Oct ↑ 9 - Non ↑ 10 - Dec	Number ↓ 1, 2, 3....	Numerical Designation → Di → Tri → Tetra	Nature of Saturation → C - C - ane → C = C - ene → C ≡ C - yne	Number ↓ 1, 2, 3....	Numerical Designation → Di → Tri → Tetra	Functional Group → - CH - Hydrocarbon - 'e' → - OH - Alcohol - 'ol' → - CHO - Aldehyde - 'al' → - C=O - Ketone - 'one' → - COOH - Carboxylic acid - 'oic acid' → - NH <sub>2</sub> - Amine - 'amine' → - CONH <sub>2</sub> - Amide → - COOR - Ester - 'oate'
	<b>Secondary functional group</b> → NO <sub>2</sub> - Nitro → NO - Nitroso → OR - Alkoxy → OH - Hydroxy → NH <sub>2</sub> - Amino → CHO - Formyl → C = O - OXO → COOH - Carboxy									



## Homi Jehangir Bhabha

**Homi J. Bhabha**, (30 October 1909 – 24 January 1966) was a nuclear Physicist, founding Director and Professor of Physics at TIFR, Mumbai. He is known as the father of the Indian Nuclear Programme. Bhabha was the founding director of two well-known research institutions, namely the Tata Institute of Fundamental Research (TIFR) and the Bhabha Atomic Research Centre both institutions were the cornerstone of Indian development of nuclear reactors and nuclear energy which Bhabha also supervised as its director.



In January 1933, Bhabha received his doctorate in nuclear physics after publishing his first scientific paper, “*The Absorption of Cosmic radiation*”. The paper helped him win the Isaac Newton Studentship in 1934.

Starting his scientific career from Great Britain, Bhabha returned to India and accepted a post of reader in physics at the Indian Institute of Science (IISc), Bangalore, headed by Nobel Laureate Sir C.V. Raman. During this time, Bhabha played a key role in convincing Jawaharlal Nehru who later became India’s first Prime Minister, to start the ambitious nuclear programme. In 1945, he established the Tata Institute of Fundamental Research (TIFR), Bombay and set up the Atomic Energy Commission in 1948, serving as its first chairman. In the 1950s, Bhabha represented India in IAEA conferences, and served as President of the UN Conference on the Peaceful Uses of Atomic Energy in Geneva in 1955.

Bhabha gained international prominence after deriving a correct expression for the probability of scattering positrons by electrons, a process now known as Bhabha scattering. His major contribution included his work on Compton scattering, R-process and furthermore the advancement of nuclear physics. He was awarded Padma Bhushan by Government of India in 1954. In January 1966, Bhabha died in a plane crash near Mont Blanc, while heading to Vienna, Austria to attend a meeting of the IAEA’s Scientific Advisory Committee.

## Chintamani Nagesa Ramachandra Rao



**C.N.R. Rao** was born in Bangalore in a Kannada family to Hanumantha Nagesa Rao and Nagamma Nagesa Rao. He completed secondary school leaving certificate in first class in 1947. He studied BSc at Central College, Bangalore. He obtained his bachelor’s degree from Mysore University in 1951, in first class, and only at the age of seventeen. He obtained a master’s in chemistry from BHU two years later. In 1953 he was granted a scholarship for PhD in IIT Kharagpur. His first research paper was published in the Agra University Journal of Research in 1954. He completed PhD in 1958, only after two years and nine months, at age twenty-four.

- Rao is an eminent scientist and a well recognised international authority on solid state and materials chemistry.
- He is currently the Head of the Scientific Advisory Council to the Prime Minister of India.
- He has published over 1,400 research papers and 45 books.
- Rao was awarded Hughes Medal by the Royal Society in 2000, and he was first recipient of the India Science Award in 2004.
- Some of the major areas of his research are transition metal oxide systems, (new synthesis and novel structures, metal-insulator transitions, CMR materials, superconductivity, multiferroics etc), hybrid materials and nanomaterials including nanotubes and graphene.
- Rao’s current passion is graphene, the new wonder material, and artificial photosynthesis.
- He was awarded ‘**Bharat Ratna**’ by the Government of India in the year 2013.

## LEARNING OUTCOMES

### *The learner...*

- ◆ Differentiates and classifies material, objects, phenomena and processes based on properties or characteristics.  
Eg: (i) Differences between Virtual & Real images, (ii) Classification of acids, bases and salts.
- ◆ Plans and conducts simple investigations or experiments to arrive at and verify the facts, principles, phenomena to seek answers to queries on their own. Concludes and Communicates the findings.  
Eg: (i) Reaction of metals with Acids and Bases, (ii) Image formation by mirrors and lenses.  
(iii) Identifies the gases evolved in the reactions. (iv) writing reports.
- ◆ Relates processes and phenomena with causes and effects.  
Eg: (i) Refraction of light, (ii) Dispersion of light, (iii) Scattering of light.
- ◆ Explains processes and phenomena.  
Eg: (i) Scattering of light, (ii) Formation of rainbow, (iii) Extraction of metals from ore.
- ◆ Calculates using the data given.  
Eg: (i) Problems based on resultant resistance. (ii) Problems based on chemical equations.
- ◆ Draws labelled diagrams, flow charts, concept maps, graphs.  
Eg: (i) Diagram of acid reacts with metals, (ii) Solinoid, motor, dynamo, furnace.
- ◆ Applies learning to hypothetical situations.  
Eg: (i) What happens if human eye lens can not accommodate?
- ◆ Analyses and interprets graphs and figures.  
Eg: (i)  $V \propto I$  Graph, (ii) Angle of deviation and angle of incidence graph.
- ◆ Uses scientific conversations, symbols and equations to represent various quantities, elements and units.  
Eg: (i) Chemical equations, (ii) Units for electric energy, power of lens.
- ◆ Measures physical quantities using appropriate apparatus, instruments and devices.  
Eg: (i) lenses, mirrors, slabs (ii) Meter scale
- ◆ Derives formulae, equations, laws and applies Scientific concepts in daily life and solving problems.  
Eg: (i) Ohm's law, (ii) Kirchoff's law, (iii) Laws of resistance. (iv) Lens formula.
- ◆ Describes Scientific discoveries and inventions.  
Eg: (i) Theorist and atomic structure, (ii) Ohm's law
- ◆ Designs models using eco-friendly resources.  
Eg: (i) Electric motor, (ii) Models of  $H_2O$ ,  $O_2$  and  $CH_4$  molecules.
- ◆ Exhibits values of honesty, objectivity, rational thinking, freedom from myths, superstitions beliefs while taking decisions, respect for life etc.