UNIT 8 THE METHOD OF SCIENCE AND THE NATURE OF SCIENTIFIC KNOWLEDGE

Structure

8.1 INTRODUCTION

In modern times, there is not a single aspect of our life that has not been influenced by science. Science intervenes to clarify our sense of wonder at distant stars and galaxies. And, at the same time, science peeps into our innermost self. Be it fine arts, history or sociology, science and technology are no longer disinterested on-lookers. Concepts of ageing and longevity, pain and pleasure, work and leisure, war and peace have all now acquired new meaning in the context of scientific developments.

As science has increasingly pervaded our lives, it has become more than a sum of physics, chemistry, biology, and mathematics. It is something more than just learning how to increase industrial or agricultural production, or inventing better machines, materials or drugs.

Science is a question of ideas, a way of thinking. It involves observation and insight, reasoning and intuition, systematic work and creative impulse. Science gives rise to an attitude of mind which is conscious of vast areas of ignorance, and is yet optimistic about human ability to unravel the mysteries that surround us. Science gives many of us a culture and a philosophy of life which leads to the pursuit of truth without prejudgement.

What is the method of science by which one gathers knowledge, sifts and interprets it, in order to lead to an understanding of nature and, to some extent, of man? What is the nature of scientific knowledge? It is important to grasp these ideas because they find applications in many other fields and often in resolving personal dilemmas. We will also give you a brief insight into the scientific approach to problem solving. The unit ends with a broad overview of various aspects of science. But the discussion does not end here. You will find echoes of the ideas presented in this unit, in the units that follow.

Objectives

After studying this unit you should be able to :

- describe what constitutes the body of scientific knowledge,
- describe the characteristic features of scientific knowledge,
- outline the scientific method and describe each of its operations.
- apply the scientific approach to solve problems of everyday life.

8.2 SCIENCE—ITS MANY FACETS

Science is at once a personal and a social pursuit. It is marked by intense creative involvement of the individual. At the same time, scientific development is affected by social conditions and demands. And, in turn, science has a powerful impact on society. It is, thus, a vehicle of social change. The human approach to life and environment has always been conditioned by a sense of wonder and curiosity on the one hand, and the struggle for survival and well being on the other. Both these basic instincts have shaped human thought from times immemorial. Science being an integral part of human thought and endeavour is also influenced by these instincts. Either of these motives could be dominant in any individual scientist. Society benefits from both, from a better understanding as also from a better control of world around us.

Science is modern in the sense that it tries to explain things as they are known today. But we know that its origin is as old as human existence. The tradition of science has existed from the earliest ages of man. It was there long before the name 'science' was invented or a 'method of science' distinct from common sense and traditional lore had evolved. We have seen that early practitioners of this tradition were found among astrologers, priests, magicians and craftsmen, not to mention the latter day alchemists. In fact, depending upon the character of societies, and the historic period of their existence, the nature of questions posed to man and his response have been changing and so has science been changing.

What is the world that science is concerned with? The world that science describes—the universe that science explores—is the natural world, the world of experience. It encompasses terrestrial and celestial, living and the non-living. Science may be regarded as a means of establishing new kinds of contacts with the world, in new domains, at new levels.

How do we establish these contacts? These are mainly through our senses. However, the range of our senses is limited. For instance, we cannot see things that are too far or too small; we cannot hear sounds that are too low or too high, and so on. There are other limitations as well. For instance, as you can see in Fig. 8.1, the perceptions gathered through our senses may be relative. Modern science has enabled us to overcome many of the limitations of our senses. For instance, limitation of the eye with respect to size or distance do not limit scientific observation because of the invention of tools like microscopes, telescopes etc. Atoms can now be 'seen' and so can the distant stars, invisible to the naked eye. With the help of scientific instruments, it is now possible to make observations which are independent of an individual's sensory perception. For instance, in Fig. 8.1 a thermometer would always record the same temperature of water in glass B, though it feels hot or cold to our fingers.

Fig. 8.1 : If you put a finger of one hand in hot water (glass A) and a finger of the other hand in cold water (glass C) for some time and then put them both in lukewarm water, you will find that the two fingers feel different sensations. The water in the glass B appears warm to the finger that was in cold water and cold to the finger that was in hot water.

New 'sounds', new 'lights', new 'spaces', new 'contacts' of various sorts—that is what the modern science is about. Our role as 'observers' of nature, as witnesses to events happening around us, has undergone a tremendous change. The ability to observe nature beyond what our senses enable us to do, gives us a feeling of nearness or closeness with natural world, as well as a sense of control over the world and ourselves.

Science helps us to constantly invade areas of ignorance and convert them into fields of knowledge. It extends our experience by the continual exploration of new domains. For example, man landed on the moon and now preparations are going on for landing men in the coming future on Mars for investigating it. Means are now available to explore the internal structure of the earth, as well as to study the structure and function of the human brain. As newer and newer problems are encountered, regions of experience are enlarged .

Apart from the basic needs, the complex world of today has varied requirements, of better means of production to reduce human drudgery, of better facilities for health care, education, communication, transport, entertainment etc. These pose far greater challenges to science than did the bare needs of food and shelter of the primitive man. These challenges lead to new areas of study which may not, at first, be clear or well defined. However, systematic study using suitable methodology, leads to an understanding of these new areas. This is how the pursuit of science is an endless search for knowledge, and an unlimited endeavour.

Science is the search for knowledge about the world, the quest for understanding it. Man has always speculated about the unknown. When speculation about an unknown area is replaced by knowledge, then that area becomes a part of science. If we do not understand an observed phenomenon we often tend to give it a mystical justification or explanation. Science enables us to 'demystify' natural phenomena, through an understanding based on facts and reason.

The body of scientific knowledge has grown tremendously in the modern times. It encompasses numerous areas. For convenience, we have demarcated these areas as biology, medicine, chemistry, geology, physics, astronomy, engineering, agriculture, and so on. However, they are all inter-related. For example, the study of biology goes down to the cell, and further to the atoms and molecules which make it. In this way it is related to the study of chemistry and physics. On the other hand, biology, especially botany, is related to forestry and agriculture implying a connection with climate and soil, and, in turn, to geography and geology. Thus, we find that scientific knowledge and experience has a connectedness at the basic level.

Further, quite often, knowledge and experience from different areas have to be pooled together for solving scientific problems or making technological advances. For example, monitoring and control of environmental pollution need the involvement of scientists from areas of physics, chemistry, biology, mathematics, sociology etc. Similarly, if we want to explore and utilise some sources of energy which do not get exhausted, like bio-gas, wind or solar energy, experts from various related areas would have to pool their knowledge and work together. Also, in the last few decades, the boundaries between different areas of natural sciences have faded. Chemical reactions, biological processes and physical phenomena are, nowadays studied by the same methods and are based on common theoretical concepts.

SAQ 1

State whether the following statements about scientific knowledge are true or false. Give your response in the boxes provided.

i) Science helps us to explore the natural world around us, continuously enlarging our regions of experience. ☐

ii) The world of science is strange and it has nothing to do with our everyday experience. ☐

iii) Through science, not only can we understand nature but can also control it to suit our needs. ☐

iv) Science has done nothing to dispel our fear, wonder and mysticism about natural phenomena. ☐

v) Since scientific knowledge is acquired through our senses, and sensory perceptions are subjective, scientific knowledge will vary from individual to individual. ☐

8.3 THE METHOD OF SCIENCE

We have seen above that science is an endeavour to understand nature and to mould it to satisfy human needs. In earlier units we have seen that, in this process, we have collected a lot of information and a distinct body of scientific knowledge has grown. Let us now see how this knowledge has been acquired. Is there any special method of obtaining scientific knowledge? If so, how is it different from the way in which we ordinarily perceive the world around us? The answer to the first question is, yes. As you have read in Unit 1, there is a 'method' of science. You are also familiar with the terms observation, hypothesis, experiment, theories and laws, which we mentioned in Unit 1. These are the various mental and physical operations that make up the method of science. Let us take a closer look at each one of these operations.

8.3.1 Observations

All of us learn a lot about the world from our observations. Our everyday experiences arising from what we see, hear, touch, taste and smell, form a part of common knowledge. For example, we observe that the sun rises in the east and sets in the west; a ball when thrown up, comes down. A farmer usually separates the good seeds from the bad ones by putting all of them in water. This is based on the observation that the good seeds sink and the bad ones float. Similarly, you can know whether an egg is rotten or good by putting it in a bowl of water. A rotten egg will always float. To make such observations is, no doubt, very useful.

Artists are also very keen observers of the world around us. Their creative art is an expression of these observations, transformed in the light of their own experiences and feelings. These, however, cannot be called scientific observations.

In science, we go beyond just the common observation and experience and try to understand how a phenomenon occurs and why it occurs. Therefore, a scientist has to be clear about 'what' to observe and 'how' to observe it. Further, the observations made by the scientists have to be correct, and independent of their sentiments and wishes. In science, subjective response must be subordinated to fact. It is in these respects that a scientist differs from an artist or a lay person.

The confusion caused by inadequate or false observations can well be imagined. It is well to remember what the great naturalist Charles Darwin said on this point, that the mischief of false theories is slight compared with the mischief of false observations. Inadequate observations can be equally misleading. For example, the believers in the earth-centred astronomy urged for years that the Copernican hypothesis could not be true. They argued that if this were so, Venus, which is a planet between the sun and the earth, would show phases like the moon. But since the phases of Venus could not be observed at that time, the Copernican astronomy was held to be false. This seemingly sound argument against the Copernican astronomy was shown to be baseless when people actually observed the phases of Venus through the telescope (see Unit 9).

Scientific observations may be about natural events. For example, the rainfall may be measured for each month for many years, to determine its pattern in a given place. Observations could be about processes created by man. For example, in order to increase the efficiency of existing machines, or to develop new machines, observations would have to be made about their design and working. Similarly, new materials like synthetic fibres, or rubber would have to be observed for their wear and tear, or any other desired property like fire resistance etc. Observations are also necessary about social phenomena. In order to analyse the socio-economic status of people in a given area or society, observations have to be made regarding the land holdings, incomes, educational level, standard of living etc. All these observations are carried out systematically, through carefully designed experiments or surveys, in order to explain natural or social phenomena.

These systematic observations are then put in order, i.e. classified, carefully recorded in the form of tables or graphs and analysed. The aim is to discover regularities and patterns in the factual information obtained. A number of questions may be posed on the basis of the observations, data, facts and figures. The importance of questioning cannot be undermined. Science progresses through asking questions and finding their answers.

8.3.2 Hypothesis

The next step is to formulate hypothesis. A hypothesis is a statement, put forward on the basis of reasoning, about the things that are being studied. It is an attempt to answer the questions that are posed. One example of hypothesis which you encountered in Unit 1, was that bees are attracted to flowers, either due to their colour, or nectar, or both (Fig. 1.4). Other examples could be that plants need sunlight to grow; or a body falls to the ground because it is attracted by the earth. A hypothesis is formulated by taking into account all the observations that are known about the phenomenon under investigation. It tries to explain the known or predict the unknown but possible features of the phenomenon. We may describe a hypothesis as an inspired guess, based on reason and experience. We may use both **inductive** and **deductive** logic to frame a hypothesis.

What do we mean by **inductive logic**? If we have direct evidence about only a **part** of the phenomenon, or some objects or situations and, if, on that basis, we infer about the properties, behaviour and other features of the **whole** phenomenon, or the entire group of objects and situations, then we are using inductive logic. For example, if we know that the population of a country has doubled in a given period of time, we may use induction to hypothesise that it will double again in the same time. Again, if we study the shadows of simple objects like triangles, rectangles and circles cast on a wall due to light from a small bulb, we may conclude that light travels in a straight line. The conclusion is a big jump in thinking, and it is a sweeping, general statement based on induction. Inductive logic can mislead also: for example to infer that all roses are red, if you happen to see only red roses in a garden is illogical. So you can see that inductive statements can have very different degrees of credibility and reliability. You cannot jump to conclusions on the basis of insufficient evidence, and the conclusions have to be further tested for their reliability.

Deductive logic may be considered as the opposite of induction. Here the reasoning is more direct. If we know a statement about a **whole** class of objects, phenomena or situations then we can logically deduce the same statement about **one** particular object, phenomenon or situation belonging to that class. Examples of deduction are: roses can be of any colour, hence some roses can be red. All birds have wings; therefore, a sparrow, which is a bird, will have wings. Deductive logic is extensively used in chemistry. For example, if a group of chemical salts exhibit some properties or behaviour, we can safely say that any salt belonging to this group will exhibit the same property or behaviour. You could say that deduction may also mislead, because in the examples how do we know that a sparrow is a bird, or a salt belongs to that group of salts. These facts would have to be established before such deductions can be accepted.

Thus, logical analysis takes us from the known to the unknown and it involves an element of isk or doubt. Hence, the hypotheses arrived at from both kinds of reasoning have to be tested before they are accepted. A major operation in the method of science is that of setting up experiments specifically designed to test the hypotheses.

8.3.3 Experiments

Experiment is an essential feature of modern science. Experiments are artificially created or contrived situations designed to make certain observations under strictly controlled conditions. The objective sometimes is to mimic nature. This allows the complexity of natural phenomena to be simplified for step-by-step study. For example, many of us might have used a bicycle pump to inflate a bicycle tube. What we do is to pump air in it by pressing the piston (see Fig. 8.2). As you can see in the figure, by pressing the piston the volume decreases, thereby increasing the pressure and forcing the air into the tyre. Similarly, if we fill a balloon partially with air and leave it in sunlight, the air inside becomes warm and expands, thus inflating the balloon. These instances show us that the volume of a gas depends both on its pressure and temperature.

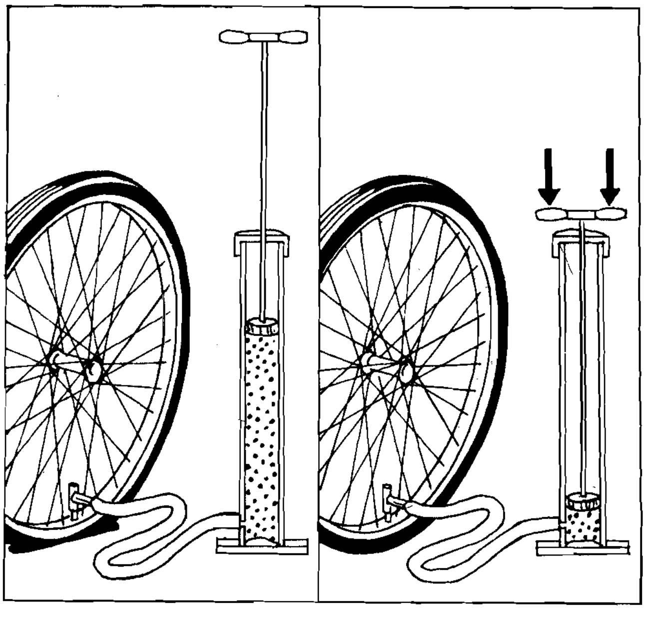


Fig. 8.2: Compression of air by decreasing its volume in a bicycle pump.

If now we want to determine exactly how much the change in volume is with a certain rise or fall in pressure or temperature, we will have to conduct an experiment in two steps. In the first step we can keep the temperature constant and observe the changes in volume with pressure. In the second step, we will have to keep the gas at constant pressure and record the change in its volume with changing temperature. These experiments were carried out by Robert Boyle and J.A.C. Charles. They derived precise mathematical relationships for the change of volume with pressure and temperature, respectively. These relationships are known after them, as Boyle's Law and Charles' Law.

The objective of an experiment may sometimes be to observe phenomena more minutely by the use of very sensitive instruments. For example, in order to study minute details of cell structure, biologists now use the electron microscope. Sometimes experiments are carried out with a sinister purpose. For example, atom bombs were dropped on two cities of Japan in 1945 not only to cause destruction but also to study how the buildings collapsed, the extent to which fires raged, and how radiations killed or injured people.

Cause and effect relationships are studied through a great variety of experiments. Great ingenuity and care is required in designing experiments so that maximum information and clearcut results may be obtained from them. The results of such experiments prove or disprove a particular hypothesis. Sometimes, a hypothesis may have to be rejected outright and a new hypothesis framed to explain the results obtained from the experiment. At other times, experiments provide additional data for refinement or modification of a hypothesis.

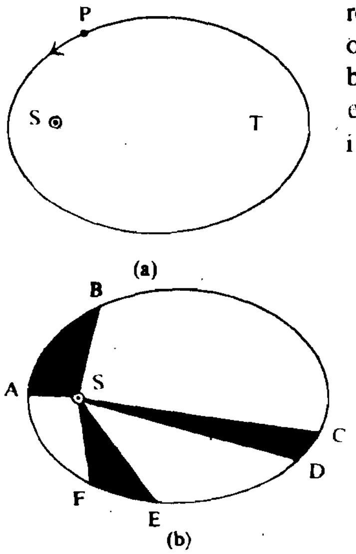
Apparatus

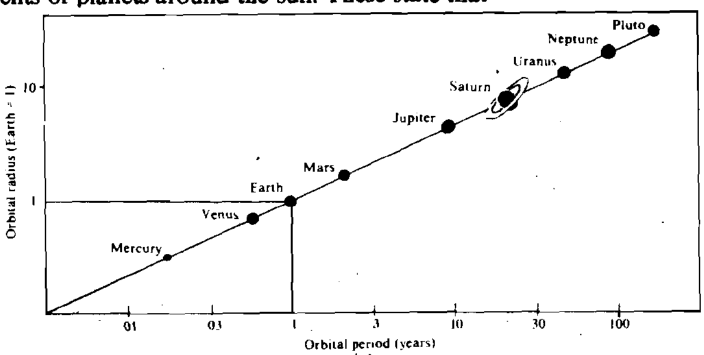
Scientists use various kinds of instruments for observation and experimentation. Instruments like telescopes, microscopes or microphones can be used to extend or make more precise, the observations made through senses. Scientists also use instruments to manipulate things or phenomena in a controlled way. For instance, distillation stills are used for purifying liquids, incubators for keeping biological samples at a constant temperature, and computers for storing large amounts of information, for complicated calculations, for designing industrial products etc. Over the course of centuries, scientists have evolved a set of material tools of their own— the 'apparatus' of science. Some of these are simply adapted from ordinary life for special purposes, like the balance, forceps or crucibles. In turn, most of the apparatus used by scientists comes into everyday use. For example, the major component of a television set is a scientific device called the cathode ray tube, which was originally fabricated to measure the mass of an electron. The commonly used pressure cooker is a form of the autoclave, an instrument used by the biologists for sterilisation with high pressure steam.

8.3.4 Laws, Models and Theories

From the observations and the results of experiments comes a good deal of scientific knowledge. But scientific knowledge is not simply a list of such results. The results are tied up and related to each other in the form of logical, coherent theories or laws. In general, a relationship between things covering results of observations and experiments over a wide range of individual cases is called a **law**. Hypotheses are accepted as 'laws' only if they are supported by a great deal of experimental evidence and there are no known exceptions to them. Some examples of laws are as follows:

i) Kepler's Laws of Planetary Motion based on the observations of the movements of planets around the sun. These state that





(c)

Fig. 8.3: Kepler's laws of planetary motion. (a) First law: a planet (P) moves in an ellipse with the Sun (S) at one of the two foci; (b) second law: It takes as long for a planet to travel from B to A and from F to E as from D to C; the shaded areas ASB, ESF, CSD are all equal; (c) third law: The size of a planet's orbit and the time taken by it to go once around the Sun are related through a precise mathematical relationship. The more distant a planet is from the Sun, the longer it takes to complete one orbit.

a) the planets move in elliptical orbits around the sun and the sun is at one of the two foci;

b) a planet sweeps out equal areas in equal times;

c) the square of the period of revolution of a planet round the sun, is proportional to the cube of its mean distance from the sun.

You may study Fig. 8.3 to understand these laws better.

ii) One of the basic laws in chemistry says that "a chemical substance in its pure form will always have the same chemical composition". For example, water is always made up of the elements hydrogen and oxygen which combine together in the ratio of 1 : 8, i.e. one part of hydrogen for eight parts of oxygen by weight. This is known as the Law of Constant Chemical Composition.

iii) Heat does not flow on its own from a cold body to a hot body. This is the Second Law of Thermodynamics.

You already know about Newton's law of universal gravitation which we have described, in brief, in Unit 6. It is a statement about how the force of attraction between two bodies depends on their masses and on the distance between them. This single statement explains not only the motion of the planets but also of a ball on the earth which always falls down when thrown up. In other words, it is applicable to the motion of a wide variety of objects.

Whenever a law appears to be broken in a new experiment, it inspires a search for new hypotheses, new phenomena or new processes that would explain the discrepancy.

There are two more terms which you will come across in scientific works, **model** and **theory**. Often scientists create a **model** to simulate the object, phenomenon or situation they study. A model is an artificial construction to represent the properties, behaviour or any other features of the real object under study. For example, the human heart is modelled as a mechanical pump, to study its structure and functions. In the earlier phases, the atom was modelled after a plum pudding, as shown in Fig. 8.4a. Later it was modified and modelled after the solar system. In a general sense, you may use a word, a picture, a formula or a symbol to model a situation. A model should communicate some information about whatever it represents. Models are useful because these represent in a simpler and familiar manner, a new, unknown and complicated object, situation or phenomenon.

Don't confuse these models with toy models of spaceships, aeroplanes etc.; or with physical models of solar system, atom, DNA molecules etc.!

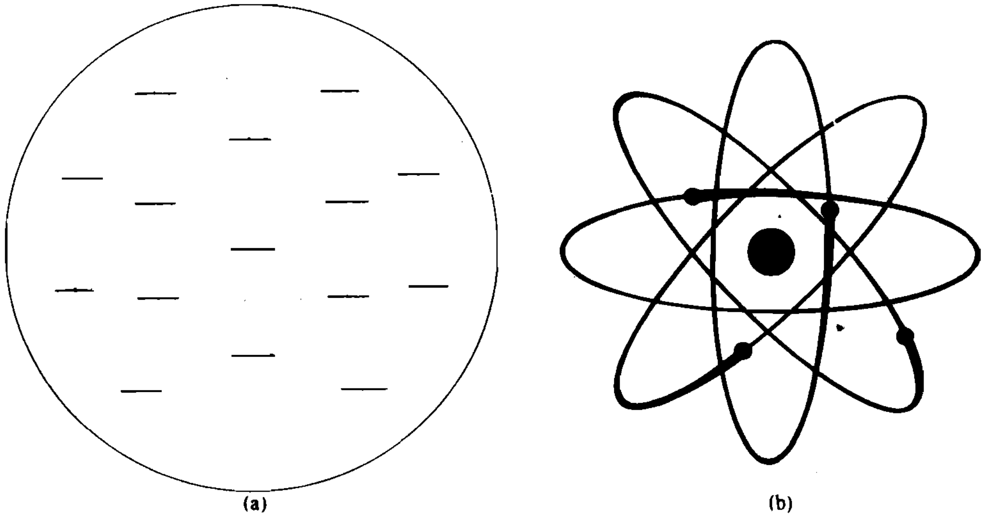


Fig. 8.4: (a) Plum pudding model of an atom. The negative charges are embedded like plums. in a positively charged sphere (shaded area). (b) the atom modelled after the solar system.

A **theory** is a set of a few general statements that can correctly describe or explain all experimental observations about the properties and behaviour of a large number of varied objects, phenomena, situations or systems. In Unit 6 you have read, in brief, about Darwin's theory of evolution, which explains how a large variety of life forms have evolved from simple living organisms. In Unit 10, you will read about the theory of how stars are born, how they evolve and die.

A law or theory can also predict observations. A classic instance is the prediction of the existence of Neptune. By 1845, the paths of all planets had been precisely calculated. All planets except Uranus were observed to follow the calculated paths. Adams in Cambridge and Leverrier in Paris reasoned that the observed deviation in the path of Uranus could be due to an unknown outer planet beyond it. Using Newton's law of universal gravitation, they predicted its size and exact path. Then on September 23, 1846 Neptune was seen at almost exactly the predicted position by Galle at the Berlin Observatory. In fact, when a new theory is propounded, great care is taken to propose an experiment which would result in a particular kind of observations if the new theory were true. In this way theories get validated or rejected.

To sum up our discussion so far, scientific work is really a chain of operations such as the following :

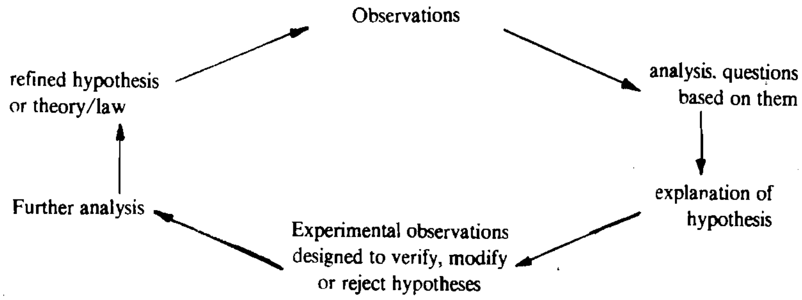


Fig. 8.5; The method of science.

8.3.5 Some Examples

Let us illustrate the method of science described above by a few concrete examples.

Example 1: It is a well known scientific fact that plants make their own food by using sunlight, carbon dioxide and water, and give off oxygen in this process. Sunlight is made up of seven different colours visible to the eye, which you must have seen in a rainbow. The question we may like to ask is whether light of all colours is equally effective in this process of making food or is light of any specific colour more effective than others? Thus, we can have a set of hypotheses such as :

i) Light of all colours is equally effective.

ii) Light of one specific colour is more effective than other colours.

The next step is to set up an experiment to test these hypotheses. The experiment can be very easily set up. We take three twigs of a water-plant like Hydrilla, submerge them in water separately and cover them with bell-jars as shown in Fig. 8.6. Then we wrap each bell-jar with cellophane papers coloured green, yellow and red, and put the three sets out in the sunlight. Thus, each of these twigs is getting light of only one colour. We assume that the amount of light reaching the twigs is same. After sometime, we observe bubbles of oxygen gas coming out of water in the bell-jar. The rate at which gas bubbles come out indicates the rate at which the plant is able to make its food.

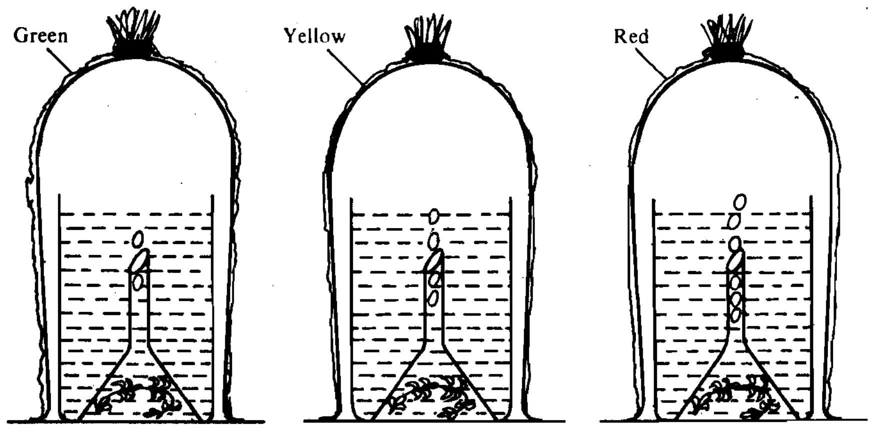


Fig. 8.6: An experiment to test whether light of a specific colour is more effective than light of other colours for photosynthesis.

In this experiment, there are four factors that are likely to vary: the three twigs could be different, the amount of water and the amount of carbon dioxide in the three bell-jars, and the colours of light they receive could vary. To test the effect of any one of these factors we have to ensure that the others remain the same. Therefore, if we are testing for the effect of light of different colours, the twigs, the amount of water and the amount of carbon dioxide should be the same in all the three cases.

We can take similar twigs from the same plant and we can assume that the amount of carbon dioxide is same in each bell-jar because they are of equal size. We can also ensure that the amount of water is same in each bell-jar. Now, if the rates at which gas bubbles come out in the three bell-jars are different, we can say that this is due to the difference in colours. In this particular case, we find that the rate is highest in the case of the twig receiving red light.

Thus, we can conclude that red light is more effective in food-making by plants, when compared with green or yellow coloured light. This result rejects the first hypothesis and gives a partial proof for the second one. We could continue this experiment and test whether other colours like orange, blue etc. are more effective than red.

We would like to add here that this is a very simple set-up. Similar studies have been carried out by scientists under precisely controlled conditions using very sophisticated equipment.

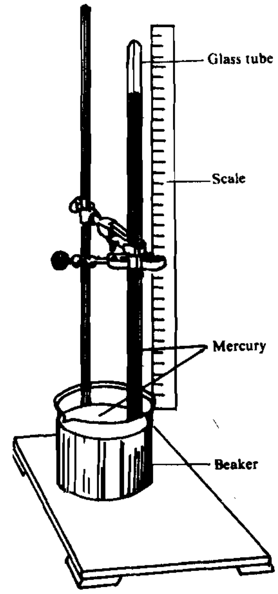


Fig. 8.7: Barometer.

Example 2: We have taken this example from the history of science. In the seventeenth century, miners and well diggers observed that it was impossible to raise water more than about thirty-two feet, through ordinary hand pumps. Galileo thought that a water column higher than this was unable to bear its weight. His pupil Torricelli (1608-47) proposed another hypothesis, that the rise of water in a pump was due to the pressure exerted by the air in the atmosphere. He reasoned that if the rise of the water was due to atmospheric pressure alone, then any other liquid would rise only upto a certain height. He then calculated mathematically, that a column of mercury would rise upto a height of thirty inches. To test this, he set up a simple experiment taking mercury in a dish and inverting a glass tube filled with mercury on it. Mercury did not rise above thirty inches, proving Torricelli's hypothesis. Thus, the barometer was invented (Fig. 8.7). It is an instrument to measure atmospheric pressure.

It is also known that high up in the mountains, the atmospheric pressure is lower than that at sea level. To further verify Torricelli's hypothesis, Pascal took the barometer up a mountain where the level of mercury fell. This showed that the low atmospheric pressure supported a lower height of the mercury column. Thus, it provided further confirmation of Torricelli's explanation.

Example 3: This one is from chemistry. It is commonly observed that if we burn a candle, it gives light, some heat and what remains in the end is a little bit of wax. It may appear as if a significant amount of matter has been destroyed in this process. However, this is not the case. In fact, in everyday processes like this, only a minute amount of matter (about 10^{-12} gm. i.e. one million-millionth fraction of a gram) converts into energy and the rest is converted to other forms of matter. How do we test this?

For this, we perform a very simple experiment (Fig. 8.8). We put a small candle in a dish, put some water in the dish, cover it with a bell-jar and weigh this assembly. Then we light the candle and allow it to burn inside the bell-jar. When it burns out, we allow the assembly to cool down and weigh it again. We find that there is no difference in the weight, though apparently some wax has been lost. What then has happened to the burnt wax and the wick?

If we look carefully, we notice some droplets of moisture and some soot on the inner sides of the bell-jar. The other substance that is formed is carbon dioxide, which we cannot see. But we can test it by putting a small amount of lime water into the dish. We observe that the lime water turns milky. This is because the lime water has absorbed the carbon dioxide that was formed, to give a white substance that does not dissolve in water.

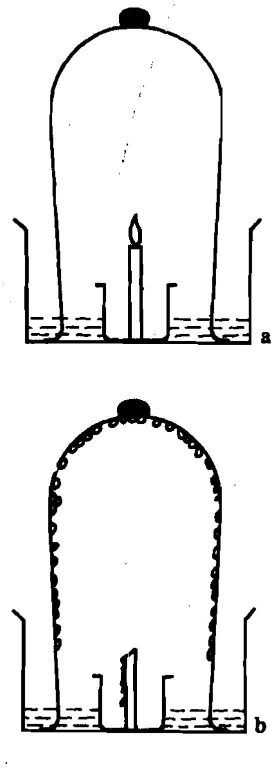


Fig. 8.8: Verification of the law of conservation of mass.

In fact, when a candle burns, water and carbon dioxide are formed and some wax is left unburnt. The amount of matter lost is so tiny that its loss cannot be detected because even the most sensitive balances available today can measure masses only upto 10^{-6} or 10^{-7} gms.(about one millionth fraction of a gram). Therefore, for all practical purposes, the total amount of matter remains unchanged. Hence, we refer to this result as the 'law' of conservation of mass in chemistry.

The sequence of operations as shown in Fig. 8.5 is general and valid for observations and hypotheses in many fields of science. However, every scientist need not follow all these steps to 'do science'. Usually, at any time a number of scientists are working on different steps of the sequence. A new scientist may enter the sequence at any stage. For example, a group of scientists had worked on a common plant like Mentha and had found out that it contained menthol, a familiar substance that we have in peppermint drops and in some toothpastes, cough syrups etc. Now, another group of scientists may study under what conditions Mentha can be grown to increase the yield of menthol, when it should be harvested to get optimum yield etc. These two groups are concerned only with observation and experimentation of practical nature. A third group of scientists might like to study how menthol is synthesised in the plant, and formulate a theory about this aspect on the basis of their study. All the three groups may work almost independently of each other, at different places, even at different times, although they may use each other's findings for their own purposes.

Or else, a group of scientists may be examining many links in this sequence representing the method of science over many years. For instance, they may be monitoring environmental pollution or they may be concerned with monsoon forecasting. Thus, in the same group of scientists, some would be collecting data on wind velocity, temperature and humidity in the atmosphere. Others would be working out theoretical models using this data and still others would carry out detailed experimental analysis of some substances in the atmosphere to prove or disprove their models.

So we find that scientists may 'do science' in different ways. Some may be good at collecting information, data, facts and figures. Some may excel in the design of experiments but may not be so good at proposing theoretical explanations. There may be some very fine theorists using data collected by others, who would not be able to identify even simple instruments in a modern laboratory, but who can apply reasoning and mathematics to arrive at new conclusions. All these scientists may be making significant contributions. But, it is not what individual scientists do or how they do it, that constitutes science. Science embodies the collective effort of all the scientists.

In short, the method of science can be summed up in the words of Einstein who was said to have remarked, 'If you want to know the essence of scientific method, don't listen to what a scientist may tell you. Watch what he does'. To this we may add, watch a large number of a variety of scientists. For, 'doing science' involves many different kinds of activities.

SAQ 2

The example given below describes a scientific investigation about a drug's efficacy against a certain disease. Identify the various operations of the scientific method shown in Fig. 8.5 that each statement represents. The statements are all jumbled up. First read them all carefully, then write your answers in the space provided.

i) A chemical substance X is accidentally spilled into a dish full of certain disease causing germs. It kills all the germs in the dish.....................

ii) In such and such a disease, the drug X is effective in around 50 per cent of the cases......................

iii) The results show that around 30% of the patients in Group 1 do not recover despite treatment. That is, out of every 100 patients being treated, 70 recover on treatment. On the other hand, 20% get well even without treatment in Group 2. So out of the 70 patients who recover, 20 may have got well even without treatment. Hence the drug is effective in only 70 per cent minus 20 per cent, or 50 per cent of the cases......................

iv) Can drug X be used to protect human beings against these disease causing germs? Yes or No......................

v) A sample population of mice, all infected with the same disease is taken. Half the mice (Group 1) are treated with the drug and the other half (Group 2) are kept without treatment. A predetermined quantity of drug is administered to the first group of mice. The number of treated mice of Group 1 that die or recover is recorded and compared with the other mice of untreated Group 2. The number of mice that recover is found to be significantly higher in Group 1 as compared with that in Group 2. A similar test is repeated, first with guinea pigs and then with a large sample of human beings in different localities......................

From the examples given above, you would have noticed that, in science, there is a wide difference in the objects, phenomena or situations studied, in the techniques used for their study, or in the kind of descriptions that result. Yet, the resulting body of scientific knowledge has certain characteristic features. Let us now discuss the nature of scientific knowledge and the features that make it distinct from other kinds of knowledge. In fact, these features are due to the specific method of objective observation, and verifying hypotheses through rigorous experimentation, about which you have just read.

8.4 THE NATURE OF SCIENTIFIC KNOWLEDGE

Science, as we have seen, is inseparable from the rest of human endeavour. In the past few thousand years of human history, an immense fund of scientific knowledge has been built up, the most dramatic scientific advances having been made in the last few hundred years. This vast storehouse of scientific knowledge encompasses everything, from particles smaller than atoms to the great system of the universe containing planets, stars and galaxies. It covers the study of plants and animals, health and disease, food and medicine and such complex problems as what life is, how the human mind functions, what the beginning and the end of the universe are etc.

As we have said before, we have been able to use this knowledge to meet our daily necessities of life, provide leisure, communicate better and faster. We are able to harness energy in a great variety of forms. From land-based creatures entirely dependent on nature for their survival, human beings have come to a stage where no barrier seems insurmountable. We have tried to traverse every nook and corner of this earth, the vast lands as well as the deep oceans and the high mountains. And now we are extending our sights upwards, not only to the solar system but to the space beyond. Our journey in space is a tremendous endeavour which has only just begun.

All such endeavours further enrich the body of scientific knowledge. Thus, scientific knowledge is never at a standstill. **It is a dynamic, and an ongoing process.** It is an **evergrowing** enterprise which will never end. This is because, in science, there is no single ultimate truth to be achieved after which all the scientists can retire.

A remarkable feature of scientific knowledge is that it is **never complete**. The more we add to this knowledge, the more questions arise about the unknown mysteries of nature. New information is, thus, continuously gathered. New theories arise if new facts can't be explained by the existing ones. Practitioners of science can never lay claim to a complete or ultimate knowledge.

We have seen that science is not static. Going a step further, we may say that scientific knowledge is also not immutable. Nothing can remain unchallenged in science. In fact, some of the most honoured scientists are those who try to alter, modify or replace existing theories by providing revolutionary evidence or argument. In this sense, science is a **self-correcting** enterprise, i.e. it is **open to change**. Many hypotheses proposed by scientists turn out to be wrong. Science is generated by and devoted to the idea of free inquiry, the idea that any hypothesis, no matter how strange, deserves to be considered on its merits. Thus, science is **not dogmatic**. It does not unreasonably insist on standing by preconceived notions, concepts or ideas that have been proved wrong through careful experimentation. *Science progresses by disproving. It has no high priests who cannot be questioned. What would be considered highly undesirable in science is the unquestioned acceptance of things as they are.*

Any new discovery, finding or interpretation of phenomena is carefully scrutinised, discussed and verified by the scientific community before its general acceptance. In this sense, the scientific 'truths' are truths by consensus, and, therefore, always tentative. The consensus is arrived at after carefully following the method of science. But, if new facts emerging from the natural world challenge this 'truth', scientists are always ready to re-examine their theories.

Last but not the least, scientific knowledge is **objective**. That is, scientific results are **repeatable** and **verifiable** by anyone anywhere if proper facilities are available. This feature of science is related to the ultimate test of any scientific statement; that it should be in accord with the observations of the natural world. *Science prefers hard facts to the dearest illusions of scientists.* To be accepted, all new ideas must survive rigorous standards of evidence. Sometimes it takes years, or even hundreds of years, before the ideas are verified. Nonetheless, in the long run, no brilliant arguments, high authority or aesthetic appeal can save a scientific theory which disagrees with experiment or observation of nature. You may recall from Unit 6 that it was this feature of objective observation in science, that led to the demolition of Aristotelian ideas about the universe. Since hard facts are independent of the prejudices and preferences of individual scientists, and experiments or observations are essentially repeatable, objectivity becomes an essential feature of scientific knowledge. In no sense is science based on experiences open only to a select few.

SAQ 3

Which two among the following statements do not characterise science? Put a cross against those. Which feature/s of scientific knowledge, discussed above, is/are described by the remaining statements? Give your answer in the space provided.

i) One day science will help us to know everything about the universe......................

ii) In the nineteenth century, it was believed by chemists that when a metal burned, something called Phlogiston escaped. Experiments showed that the residual material had more weight than the original metal. The adherents of the Phlogiston theory explained this by saying that Phlogiston had negative weight! Repeated experiments showed that metals combined with oxygen to make chemical compounds called metal oxides: The Phlogiston theory was thus set aside......................

iii) A famous astronomer claimed that he had discovered a new galaxy in the distant universe. Other groups of scientists could not confirm this observation. Yet, the astronomer was believed because he was a great authority in his field......................

iv) We are all familiar with pasteurised milk. This means that the bacteria in milk are destroyed by heating it to a high temperature. This practice has its origin in a famous experiment of Louis Pasteur, in which he showed that living organisms could not be created spontaneously. Pasteur boiled water, thus destroying the germs in it, filled it in a flask and sealed it. When, after many days, water in the flask was examined under a microscope, no germs were found in it. This would not have happened if germs were spontaneously created out of water. Pasteur's experiments were repeated in several laboratories and it was confirmed that only life could beget life......................

v) Well upto the end of the nineteenth century, it was thought that the atoms were indivisible. In the early twentieth century, experimentalists showed that atoms were made up of electrons, protons and neutrons. In recent years, many more elementary particles have been discovered......................

8.5 SCIENTIFIC APPROACH TO PROBLEM SOLVING

The scientific method and the features of scientific knowledge described above are in no way restricted to the domain of scientists alone. These characterise a scientific approach to solving problems whether they are scientific, economic, social or even personal. These attributes of science reflect an attitude of mind which is basically rational and can be adopted by anyone who has understood them. Thus, scientific approach can, and indeed should, form the basis of not only solving different kinds of problems in laboratory situations but also in everyday life.

Even if it seems repetitive, let us once again outline the scientific approach to problem solving. If we are faced with a problem, what should be our mental attitude towards it? First of all, we should approach it with an open mind, without any preconceived notions, whims or prejudices. Then, no external pressures of authority should be allowed to affect our observations or analysis.

What methods should we adopt for solving the problem? While analysing it, we should try to look at it from all possible angles, consider all the factors involved, ask all possible questions and gather all data and facts about it. Doubt and scepticism are the hallmarks of scientific approach. We should not accept blindly, on faith, any statement without examining it critically. We should base our analysis on rational and objective thinking and then come to conclusions. In no case should we rush into hasty decisions. We should also avoid making generalisations on the basis of insufficient evidence.

Further, we should not consider our conclusions as the last word on the said problem. If any new facts or evidences come to light which alter our results, we should always be prepared to revise our conclusions. We should be flexible in our attitude and avoid being dogmatic in our views regarding any matter. Hard work, discipline and basic integrity are certain other attributes which we will have to adopt if we are to make the scientific approach a process of thinking and a method of acting, in other words, a way of life.

We will now consider certain examples from our everyday life which can help in clarifying the ideas presented above. There are many social problems associated with developmental projects wherein it becomes imperative to adopt a scientific approach.

Let us take the problem of choosing a location for an industry to manufacture chemicals. Apart from the technical aspects, social factors would also have to be taken into account while taking this decision. For example, how densely populated that area is, how the displaced people will be resettled, what the industry's effect on the surrounding environment will be, how and where would its waste products be disposed of, the wind direction in case there are any toxic leaks, where would the workers be housed, what industrial safety measures would be needed and so on. Unless we take all such factors into account, weigh the pros and cons scientifically and then take decisions, we will never be able to avert disasters like the Bhopal gas tragedy of December, 1984. There can be many other similar examples, like setting up nuclear power plants, huge hydel projects, and other industrial projects which involve a careful planning based on a scientific approach.

This approach is applicable in social sciences too. For instance, a few years ago a study was carried out to test the general belief that 'student unrest is caused by first generation learners whose parents are not educated'. Extensive data about such students was collected and the analysis showed that this belief was wrong. Even in our everyday life, we use this approach to optimise our efforts. For example, if you have to meet three persons in different parts of the town, you can plan your visit to optimally use your time and money. Housewives often optimise their monthly purchases by checking the prices and quality of goods at various stores; if a cheap store is far away, they have to decide to buy a larger quantity so as to justify more travelling expenses.

Problems often crop up in our society when people living in different regions, speaking different languages, following different religions or social practices develop prejudiced opinions about each other. You may have come across all kinds of prejudiced generalisations made on the basis of very little evidence, such as, 'North Indians are brash', 'South Indians are weak minded', 'Gorkhas are brave', 'Punjabis eat very rich food', 'Scheduled Castes are dull headed', 'Poor people are dishonest' etc. All these notions would not have arisen if we were scientific in our approach, because evidence and analysis indicates that these are not generally true.

Often in a region, people fight with each other on issues that are thoroughly irrational and illogical. Much of the rioting and bloodshed in communal violence can be avoided if the people involved don't blindly believe in rumours or get swayed by those who preach hatred. If one used scientific reasoning and logic, examined facts and the basic issues underlying these incidents, such as uneven economic development, role of vested interests in fanning riots etc., one would never become a party to such crimes. Instead, one could always help in averting these situations.

In our own lives, too, we should adopt a scientific approach to solving problems. For example, if things go wrong in relations between people, they could always sit together and analyse their problems in a rational and objective manner instead of being carried away by emotions and adopting the dogmatic attitude of 'I am right, you are wrong'. Similarly, if at any time of our lives, we do not do well and are faced with problems, we should not lose heart and become fatalistic. Instead, we could show a positive approach of making an effort to understand what's wrong, ask searching questions, seek their answers and try to proceed in a rational way. There are many problems around us relating to health and nutrition, environment etc. where it would serve us well if we made the scientific approach an integral part of our thinking and living.

To sum up this discussion, using the scientific method to solve our day-to-day problems would mean to shun the attitudes of dogmatic beliefs and arrogance on the one hand, and helplessness, despair and diffidence on the other. It would do us good to adopt the positive attitudes of curiosity, a questioning bent of mind, confidence in our ability, open-mindedness, rational thinking, objectivity, flexibility and above all, humility. If we are successful even partially in this endeavour, we would have understood the essence of scientific method.

SAQ 4

In the following situations, which of the responses would you term as scientific and which ones as unscientific. Indicate it by putting S (for scientific) or U (for unscientific) against each statement.

a) Somebody comes and tells you that he has seen a bright light descending from the skies to the earth on previous night. You

i) believe him and go and tell another person that you have seen the light too. ....

ii) question the person in detail and try to find out the facts. ....

b) You are in an organisation and some persons working under you complain about one of their colleagues. You

i) suspend that person right away. ....

ii) don't pay any attention to the complaints as you rather like that person. ....

iii) conduct an enquiry, gather the facts and then decide. ....

c) A child in your family is very ill and seems to be dying. You

i) believe that it is God's will and nothing can be done about it. ....

ii) take the child to a witch doctor for treatment, thinking that she or he can cure the child. ....

iii) take the child to a hospital for proper medical treatment. ....

iv) bring some medicine from a quack after telling him the symptoms. ....

8.6 A REFLECTION ABOUT SCIENCE

We have said many things about science, and there are many other things you may know about it on your own. Now is the time to reflect about the nature of scientific knowledge, of scientific work by individuals, and of the limitations of science.

We have seen that there is a tremendous store of knowledge which has been created in the short spell of perhaps a few thousand years. This knowledge has helped us to do wonderful things like flying in the air, landing on the moon, transmitting pictures over long distances. increasing the average span of human life to over 70 years in some countries. It has also enabled man to engage in mass destruction. There are millions of people today who are engaged in various aspects of using this store of scientific knowledge-educators, engineers, doctors, instrument designers and so on.

There is, however, the other side of scientific work which is creative. New knowledge is being discovered all the time. Millions of people are working to enlarge the store of knowledge, be it about the cosmos, or the elementary particles, or the nature of genes and chromosomes in living beings. There are those working with huge apparatus scanning the skies or smashing tiny particles against each other, and those working with pencil and paper to propound theories by condensing a great variety of observations into simpler statements of laws of nature. If the first kind are mostly using logic and reason, the creative workers are additionally using the power of imagination and intuition. It is also true that a large number of scientists are engaged simultaneously in both kinds of activity, because no hard and fast line can be drawn between them.

We have seen that the struggle of the scientists to penetrate the sphere of the unknown can rightly be called a quest for truth. It is to be realised that the result is beautiful—beautiful in its expression, and fascinating in the further possibilities that it opens up. Truth and beauty are one and the same thing, according to some philosophers. In science it is true that a good deal of theoretical and experimental work which led to significant findings was triggered off by the considerations of symmetry or elegance in an equation. It gives as much thrill to a creative scientific worker to see his experiment yield new results, or to be able to express diverse scientific facts in a simple equation, as the painting of a picture to an artist or the conceiving of a new raga to a musician. The subjective experience of "doing" science, and the motivation of the scientists are as important in their creative work as the experience of a poet.

We have also tried to show that while there is tremendous variety in scientific work, and scientists of different specialisations use a great variety of methods, there is also a set of common features in the methods that are followed. One can speak of a method of science in this sense, and if one considers the attitude of mind which leads to successful endeavours in science, one could call it as the temper of science. In India one of our great promoters of science, Jawaharlal Nehru preferred the word 'scientific temper' because it can be applied to many areas of social and personal life. If the great scientific enterprise has succeeded because certain broad methods of enquiry have been used, or problems have been tackled by certain attitudes of mind, it is worthwhile to examine these so as to benefit from them in all other spheres of life.

We have tried to show that "objectivity" is one such characteristic of the scientific temper which implies approaching a problem with an open mind, without trying to fit our personal whims, fancies or prejudices into the result. It also implies, on the other hand, that social pressures or the existence of some great authority already having an opinion on the question, should not affect our scientific approach to a problem. For example, let's suppose that 5000 acres of land is to be cleared for making a station for testing missiles. Scientists may be asked to figure out the consequences of changing the pattern of land use on the environment, and also on human beings who may presently be living in that area. The scientists should neither be carried away by emotion, nor unconsciously justify the clearing of land, or yield to any pressure by politicians or local inhabitants. Great integrity is part of objectivity in making a scientific study. Of course, it does not mean that human problems or even suffering likely to be created by the change of land use would not be carefully assessed in the study and given due weight in arriving at the conclusions.

In the course of scientific work, one has to be flexible and ready to change from one kind of approach to another if the first approach does not succeed. Change is the very essence of all existence and a scientific attitude is that which is not daunted by it. In fact, science as a whole is a harbinger of change, and it flourishes in a society which is non-dogmatic and is in search of change.

In the scientific temper, reason and logic have a major part to play because they are the basic tools of all analysis. But imagination and even speculation are simultaneously used to tackle every problem.

A few limiting features are also very important to note. Scientific knowledge is not complete, nor is it ever likely to be final. This is because our experience so far has been that as ignorance is removed and knowledge is established in any sphere, fresh questions are posed before our intellect, or a new area of ignorance is uncovered. For example, when it was established that matter consists of particles and voids, we talked of "atoms" or elements; when atoms were deeply investigated they were found to be made up of electrons, protons and neutrons; and when these have been further scrutinised, more fundamental particles have been discovered.

The search goes on. Scientific knowledge increases by leaps and bounds, but each advance opens up fresh avenues of enquiry. That is why scientists cannot be fundamentalists, they will always be enquiring into new areas. Nevertheless, in a scientific sphere, the best that we know is represented by the current knowledge of science. One cannot say that if present scientific knowledge has no answer to a problem, one should believe whatever a non-scientist says about it. If the cure for cancer has not been discovered, a quack or a godman cannot cure it either. A profound trust in science, in spite of its limitation, is the sign of being civilised.

One should also know that there are spheres of knowledge other than science—there is knowledge of the individual in terms of his feelings, behaviour, dreams and aspirations. This actually borders on scientific knowledge of the body and the brain; there is knowledge of human behaviour in groups and habitations; there is knowledge of history, of economic and political systems, international affairs, and so on. Knowledge of one sphere impinges on that of the other—economics and international affairs involve science and technology in a big way. It is because of this reality that a scientist being also a citizen, possessing access to a very powerful field of knowledge, must acquire other kinds of knowledge, for example of sociology, economics and politics.

It is again because of many different facets of knowledge that there is a need to integrate it and develop what may be called a "philosophy" or an "ideology" or a "world-view". Effective use of science can be made to overcome shocking deprivations which hundreds of millions of people living in the old colonies of the "developed" countries suffer, such as malnutrition, ill health, lack of drinking water and sanitary arrangements, lack of shelter from sun and rain. But, for this scientists have to possess social consciousness, and a spirit to change society for the better.

Some people say science has to be combined with "spirituality". Now, if spirituality means ability to distinguish between good and evil, falsehood and truth, social justice and mere pursuit of profit, corruption and integrity—no one could contest the statement. But if "spirituality" includes blind belief in certain dogmas, accepting superstition and obscurantism, or belief in supernatural powers then, obviously, the statement is not true. Scientific knowledge has come to be established, and scientific attitudes have come to be refined precisely by a struggle against unfounded, preconceived notions and beliefs, and the ideology of ignorance.

8.7 SUMMARY

- In this unit we have discussed some aspects of the nature of scientific knowledge. Scientific knowledge is objective, evergrowing, open to change, nondogmatic and never complete.
- We have given an idea about the method of science and its various operations, like objective observation, framing hypotheses, experimentation, verification and refinement of hypotheses.
- We have also shown how the scientific approach can be applied to the world around us and how using it we can solve our social and personal problems.

8.8 TERMINAL QUESTIONS

1) Observe the figures carefully and answer questions about them in the space provided :

   i) Where is the missing piece of cake in Fig. 8.9?

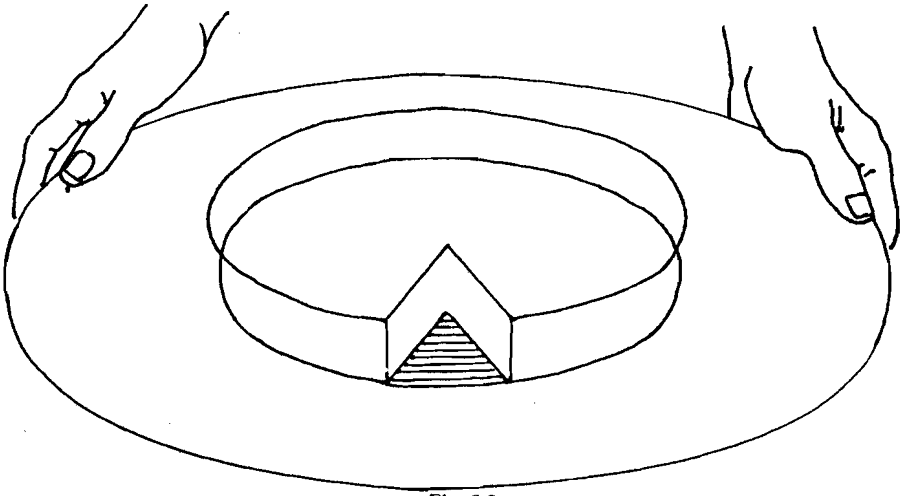


Fig. 8.9

....

....

   ii) How will the solution taste to the man in Fig. 8.10?

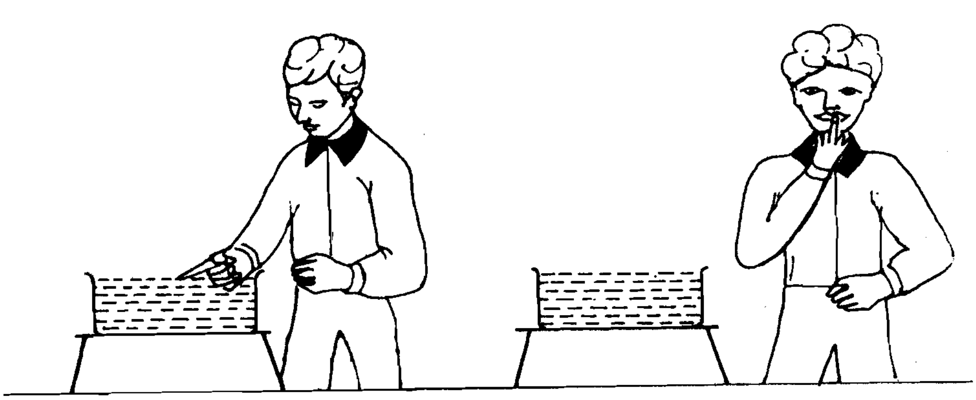


Fig. 8.10

....

....

iii) Which distance in Fig. 8.11 is longer, AB or AC?

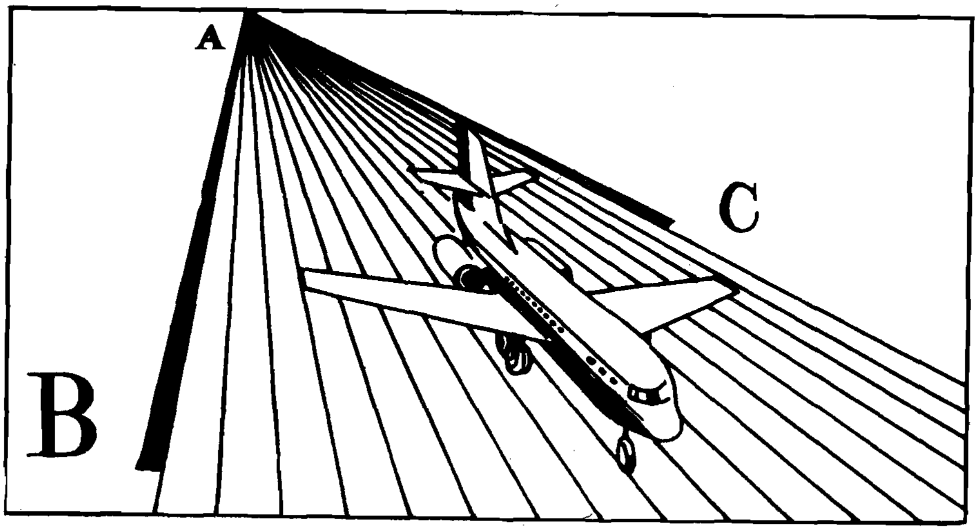
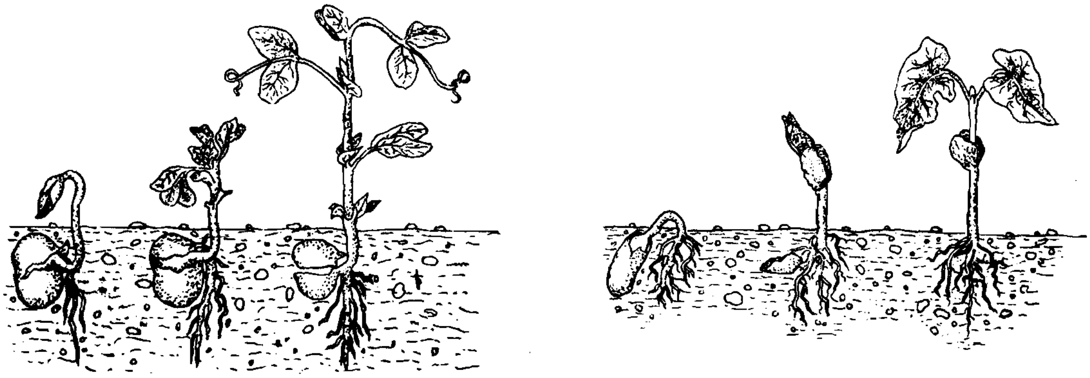


Fig. 8.11

....

iv) What is the difference between the germination of seeds in cases (a) and (b) shown in Fig. 8.12?



(a) Fig. 8.12 (b)

....

2) State at least one hypothesis based on each of the following observations in the space provided.

i) Some plants were kept in a closed dark room where no light could reach them. The plants wilted and died in a few days time.

....

....

....

ii) In a rice growing area, it was observed over a period of few years that infant mortality rate was highest in the months of July and August when the rice sowing operation was in full swing. About 40% children born during this period died within the first month after birth or were still born.

....

....

....

iii) It is observed that chameleons or moths living in different surroundings have different colours.

....

....

....

3) i) Test the hypothesis that all the circles are placed in the lower right corner of Fig. 8.13. Write down your result.

....

....

....

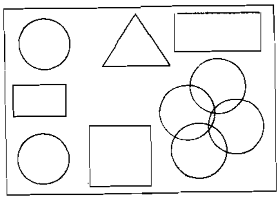


Fig. 8.13

ii) Suggest a method to test the hypothesis: 'Illiterate mothers have more children than mothers with university degrees.'

....

....

....

4) State in the space provided, the conclusions that you derive from the experiments described below?

i) The stalk of a white flower is divided into two parts. One half is put in one glass containing coloured water, the other half in another glass containing plain water, as shown in Fig. 8.14. After a few hours, one side of the flower becomes red.

....

....

....

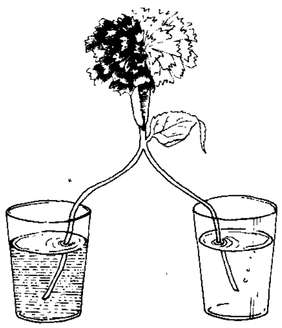


Fig. 8.14

ii) A serum containing pneumonia-causing bacteria is injected in a sample of mice, all of which die after a few days. The same serum is boiled thoroughly and again injected in another sample of mice. None of the mice die this time (see Fig. 8.15).

....

....

....

iii) When a turmeric stain made on a cloth by a vegetable cooked in oil is washed in water and hung to dry in sun, the stain remains. If the cloth is washed with a detergent and hung to dry in shade the stain remains but if dried in bright sun, the stain disappears.

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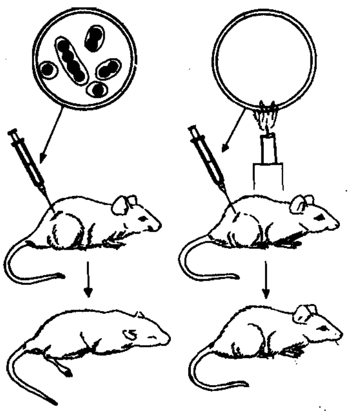

Fig. 8.15

8.9 ANSWERS

Self Assessment Questions

1) i) T ii) F iii) T iv) F v) F

2) i) Observation ii) Theory iii) Analysis of results iv) Question and hypothesis v) Experiment

3) i) x ii) Objective and open to change iii) x iv) Objective v) Never complete, open to change

4) a) i) U ii) S
b) i) U ii) U iii) S
(c) i) U ii) U iii) S iv) U

Terminal Questions

1) i) Turn the figure upside down.
   ii) The man can't tell it because he has not licked the finger that he dipped in the solution.
   iii) Both are equal. You'll find out if you measure them.
   iv) In case a), the seed leaves remain under the ground; in case b) they have come above the ground.

In all these examples, you would have noticed that observations should be done carefully, you should not always, rely on your sensory perceptions but on measurement, and observations should be accurate.

2) i) a) Plants need light to grow.
   ii) a) The expectant mothers may be malnourished.
   b) Mothers continuously sow rice in a back breaking kneeling posture which puts a strain on them.
   iii) a) Chameleons or moths adapt themselves to the surroundings to protect themselves from predators.
   b) The surroundings cause the change in chameleons or moths.

3) i) 'Far more circles are placed in the lower right corner than elsewhere.'
   ii) A large sample of illiterate and university educated mothers representing varied socio-economic backgrounds belonging to different regions, religions and castes should be taken and the sizes of their family found out to arrive at any result. You could add to this answer.

4) i) Water from the glass goes up through the stalk into the petals of the flowers.
   ii) Boiling the serum destroys the pneumonia bacteria completely.
   iii) The detergent soap dissolves the oil and the bright sun bleaches away the colour of turmeric on the cloth.

GLOSSARY

acoustics: the study of sound

alchemy: a medieval chemical art and speculative philosophy aiming to convert other metals into gold, to discover a universal cure for disease and to discover a means of indefinitely prolonging life

amalgamation: making an alloy of mercury with another metal

apartheid : a policy of segregation or discrimination on a racial basis practised even now in South Africa

arcuate: curved like a bow

atlas: a bound collection of maps, tables, charts etc.

atmospheric pressure: pressure exerted by air in the atmosphere

atomic energy: energy that is released corresponding to the decrease in the mass of an atomic nucleus when two atomic nuclei combine to form it or due to the fission of heavy atomic nuclei

bacteriology: the study of bacteria

calligraphy: the art of producing elegant handwriting

cartography: the science or art of making maps

caulking: stopping the seams and making them watertight by filling with a waterproofing material

cell: the unit of life; all living organisms are made up of cells

chromosomes: thread-like bodies that occur in the nuclei of living cells: they carry genes.

celestial: of the sky, heavenly

cosmos: the universe

crystallisation: the process of forming crystals

dioptrics: studies about the passage of light from one medium to another

distillation: a chemical process used for purification or separation of substances

dynamics: the study of the motion of bodies under the action of forces

electronics: the study of electrons, their behaviour and effects

electron microscope: an instrument similar in purpose to the ordinary microscope; it is different in design and is able to produce a much more magnified image of an object

elementary particles: the basic particles of which all matter is composed

environment: surrounding objects, natural and social conditions, circumstances of life of person or society

feudal: related to feudalism; feudalism was a system of political organisation which had as its basis the relation of lord to serf; all land was held by the lords in fee and the forced service by tenants, i.e. the serfs, was its characteristic feature

galaxies: luminous bands of stars, gas and dust existing in space

genes: unit of heredity in chromosome, controlling a particular inherited characteristic of an individual

geography: a science that deals with the earth and the life on it

geology: a science that deals with the history of the earth and its life, especially as recorded in rocks

gradation: a scale showing regular degrees

grafting: causing a detached portion of a living plant to unite with the main stem of another plant

horticulture: the science and art of growing fruits, vegetables, flowers, or ornamental plants

hydraulics: the science dealing with practical applications of water or other liquid in motion through pipes etc.

lathe: a machine for cutting and shaping materials

latitude: angular distance north or south of a point from the earth's equator measured upon the curved surface of the earth

logic: science of reasoning

longitude: the angle which the meridian through the geographical poles and a point on Earth's surface makes with a standard meridian (usually through Greenwich) is the longitude of the point

magnetism: science that deals with magnetic phenomena that includes the attraction for iron observed in a magnet.

meridian: a great circle on the surface of the earth passing through the geographical poles and any given place

microscope: instrument to magnify image of objects, to reveal details invisible to the unaided eye

mordant: a chemical that fixes a dye on a substance

mysticism: obscure or irrational speculation

nuclear science: science dealing with the study of nucleus of an atom

obscurantism: deliberate vagueness and an opposition to the spread of knowledge

observatory: a place equipped for observation of natural phenomena, as in astronomy

optics: the science that deals with light, its properties, behaviour, etc. and other phenomena associated with it

orthopaedics: the area of medical science that deals with the correction or prevention of deformities in the skeleton

oxidation: the act or process of combining a substance with oxygen or removing one or more electrons from the atom, ion or molecule

palaeobotany: a branch of botany dealing with fossil plants

pneumatics: a branch of mechanics that deals with the mechanical properties of gases

quadrant: an instrument for measuring altitudes (heights)

radar: an abbreviation of the words 'radio detection and ranging'; a device for locating an object by means of radiowaves reflected from the object and received by the device

renaissance: revival, rebirth; a movement or a period of vigorous artistic and intellectual activity

resist: chemical agent applied to parts of cloth that are not to take the dye

rhetoric: the art of speaking or writing effectively

serf: a member of the servile feudal class bound to the soil and more or less subject to the will of his lord

sericulture: the production of raw silk by raising silkworms

soldering: joining metallic surfaces by a metal or metallic alloy

specific gravity: the ratio of the density of a substance, i.e. its mass per unit volume, to the density of a substance like pure water taken as standard, when both densities are obtained by weighing in air

steppe: level and treeless land

sterilise: to free from living germs

stimulus: any agent that directly influences the activity of living organisms—as by exciting sensory organs, causing muscular contractions etc.

telescope: instrument using lenses or mirrors or both to make distant objects appear nearer and larger

terrestrial: of the earth

theology: rational interpretation of religious faith, practice and experience

topography: detailed description of the natural and man-made features of a place or region on maps or charts

trabeate: designed or constructed of horizontal beams

trigonometry: the study of the properties of triangles and of trigonometric functions like sine, cosine, tangent, etc. of an angle, and their applications

FURTHER READING

1 *Medieval India*, A Textbook for Classes XI-XII, Part I, Satish Chandra, NCERT, 1986.

2 *Medieval India*, A Textbook for Classes XI-XII, Part II, Satish Chandra, NCERT, 1986.

3 *The Story of Civilization*, Volumes 1 and 2, Arjun Dev, NCERT, 1987.

4 *Science and Society an Anthology*, compiled and edited by A.K. Jalaluddin, U. Malik and R.P. Bhatia, Rajkamal Prakashan Private Limited, 1977.

5 *Science, Nonscience and the Paranormal*, edited by Dr. H. Narasimhaiah, Bangalore Science Forum, 1987.

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