स्वाध्याय स्वमन्थन स्वावलम्बन

UTTAR PRADESH RAJARSHI TANDON OPEN UNIVERSITY

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UGFST-01
FOUNDATION COURSE IN
SCIENCE & TECHNOLOGY

SECOND - BLOCK

Emergence of Modern Science

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।। सरस्वती नः सुभगा मयस्करत् ।।

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UGFST - 01

Foundation Course in Science & Technology

Block

2

EMERGENCE OF MODERN SCIENCE

BLOCK 2 EMERGENCE OF MODERN SCIENCE

In Block 1 we had briefly traced the history of science from the very beginning of human society to the times known as the Iron Age. This was done within the conceptual framework that we had set forth right in the beginning. We tried to examine the interaction of science and society during these epochs. We will continue the story in this block and describe the emergence of modern science.

The roots of modern science can be traced to the revolutionary changes in European society in the mid-fifteenth century. These changes swept away the ignorance and despair of the Dark Ages. They provided conditions for an altogether new outlook and major breakthrough in science and its utilisation, which has been described as the Scientific and the Industrial Revolution. However, we begin this block with the Arab contribution to science because the scientific traditions of the classical ages were kept alive by the Arabs. They transmitted these to the Europeans and also to the Indians. In many areas they also used, for the first time, the experimental method and the rational treatment associated with modern science.

We will describe the scientific developments in India in the medieval, colonial and modern times and look for the reasons why, after the sixteenth century, India lagged behind Europe in its scientific and technical endeavour. As we reach our own times, history blends into remembered experience and science becomes an extremely complex social phenomenon. It is only in the twentieth century that science has come into its own, with far more work having been done in this century than in the whole previous history. Science has a distinct body of knowledge and its own method to acquire it. If we want to develop an understanding of modern science in the social context and wish to use and develop science to the full in our society, we must acquire a grasp of the scientific method and the nature of scientific knowledge. These two aspects of science form the theme of Unit 8 of this block. While reading this block, you should keep in mind the objectives spelt out in Block 1, and extend those to the medieval and modern times. In other words, you should be able to :

- understand the development of science and technology in the medieval and modern times,
- understand the interdependence of science and society, and the emergence of modern science in this context,
- appreciate the scientific method and use the scientific approach to problem solving,
- realise that science is an objective, evergrowing, never complete and non-dogmatic systematised body of knowledge which is always open to change.

It would also be instructive to watch the video-programme 'The Method of Science', which depicts the scientific method and its application in various areas. The video cassette will be available at your study centre.

UNIT 5 SCIENCE IN THE MEDIEVAL TIMES

Structure

5.1 INTRODUCTION

We have seen in Unit 3 that the centre of science had shifted to the east for about 500 years following the collapse of Rome. We also saw in Unit 4 that the period from the fourth century B.C. to the fifth century A.D. was an age of great cultural advance in India. Science and technology flourished in India during the period of the Guptas (320—480 A.D.). However, by the sixth century A.D., India once again developed a complex religious and caste system. Slowly, the rigid social structure, prevailing religious dogmas and the crumbling empires led to a stagnation in Indian society. The development of science also slowed down in this process.

Meanwhile, between the third and the seventh century A.D., Europe had seen the rise of Christianity. In its early phase, Christianity was associated with democratic tradition and had a popular appeal. However, soon the Roman Empire took over the Christian Church and adopted the Christian faith. This, as we shall see, stifled the growth of science in Europe. Even as the ancient Indian and Roman cultures decayed, a positive development was taking shape elsewhere in the world. The advent of Islam in the seventh century A.D. provided a great stimulus to the Arab culture and science. Even though the Islamic culture had started decaying by the eleventh century A.D., the fruits of Islamic science were not wasted. When Islam came to India in the eleventh century, a large body of knowledge came into Indian possession. This, in a way, shaped the developments in Indian science in the medieval times.

In this unit we will cover a rather long period in the history of science, from around the seventh century A.D. to the end of the eighteenth century A.D. We will, very briefly, touch upon the history of Christianity and then see how the Arab renaissance and the rise of Islam helped in the flowering of Arab science. In the latter part of this unit, we shall concentrate on the development of science and technology in medieval India.

Objectives

After studying this unit you should be able to :

- describe the contribution of Arabs to the body of scientific knowledge,
- describe and assess the level of development of science in medieval India,
- analyse the factors that impeded the growth of science in India in the medieval times.

5.2 THE ARAB RENAISSANCE

We have seen in Unit 3 that, by the end of the second century A.D., the Roman Empire had begun to decline. Its economy was overburdened by a huge army. Stagnating production had led to the imposition of heavy taxes. Consequently, the social structure became extremely exploitative.

Christianity, most probably, grew out of the distress and protest of the slaves and other common people of the Roman Empire. It is no accident that it first arose among the Jews who were the most oppressed. They were also imbued with the spirit of rejecting any compromise with the powers of this world. The popular appeal of Christianity lay in its outward submissiveness combined with absolute determination to have no part in the prevailing oppressive and sinful society. This also led to its persecution, which gave it even greater appeal and strength. Christianity spread rapidly among all people. Very soon it was no more confined to the lower classes. Its teachings became influenced by the prevalent social ideas. Within a few centuries, the Church itself established the rule of dogmas and became a partner in maintaining the state. By the sixth century A.D., people on the eastern borders of the Roman Empire began to identify Christianity with an alien, hostile and oppressive government.

However, we find that to these negative factors, there was soon added a positive one—the appearance and spread of a new religion, Islam, in the seventh century A.D. Islam incorporated what was most agreeable in Christianity. With its message of universal brotherhood, simple but exacting personal conduct and a sure hope of realistic paradise for the believer, it soon found popular support. As the Arabs from Syria and Iraq came to conquer lands stretching upto the Mediterranean with the message of Islam, they very often found little resistance from the local population.

Soon a vast area stretching from Spain to India came under the influence of Islam (Fig. 5.1) and, thus, extensive trade and cultural exchanges became possible. The flourishing trade gave rise to demand for commodities. This, in turn, encouraged invention of new techniques for making steel, paper, silk, porcelain etc.

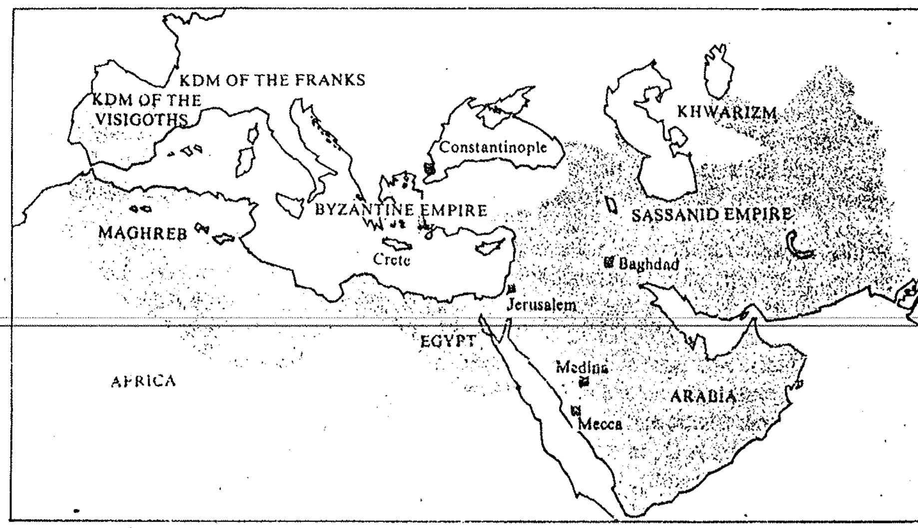


Fig. 5.1: Expansion of Islam upto 750 A.D.

Christianity had, by then, become identified with a decaying and corrupt empire. Therefore, scholars and intellectuals from the eastern and African parts of the Roman Empire started escaping to Persia which was becoming the new centre of learning and scholarship. These people were largely heretics and were safer from persecution under Muslim Caliphs than under the orthodox Roman Empire. In 431 A.D., the Syrian monk Nestor and his followers who challenged the Christian dogma were condemned and persecuted. They fled to Persia where a vigorous culture was being promoted by the Sassanian kings. Similarly, the Egyptian monk Eutyches of Alexandria (378—454 A.D.) and his followers had to flee from Egypt to Persia under pressure from the Church. Both these scholars made significant contributions to mathematics and astronomy. In the next section, we will describe how Arab science took shape. We will also see what contributions the Arabs made to the world of science.

5.2.1 Arab Science

What was crucial about this new Arab-centred civilisation was its willingness to examine and understand the classical scientific and philosophical traditions of the Greeks in the context of its new and vigorous culture. This was possible because of the written documents which reached the Arabs with the spread of the Roman Empire. Besides, they also had a strong feeling of being the heirs of the ancients. They traced the store of knowledge step by step back to the original Greek works. They translated these writings, absorbed them and developed them further. Caliph-al-Mamun founded a bureau of translation, Dar el Hikhma, where the great scholars Hunain ibn Ishaac and Thabit ibn Khurra prepared Arabic texts of most of Aristotle's and Ptolemy's writings and other major Greek classics of science. These scholars prospered under the patronage of the great Caliphs, al-Mansur, Haroun-al-Raschid, al-Mamun and al-Mutawahkil. They also translated the Indian medicinal, surgical and astronomical texts. This was aided by the extensive travels undertaken by merchants, travellers and scholars such as al-Biruni (973-1048 A.D.), who brought back the knowledge of local practices from the distant lands of India, Greece and China.

Al-Mansur, al-Mamun, Haroun-al-Raschid and al-Mutawahkil were Muslim Caliphs of the Abbasid dynasty, who ruled Persia between 754 and 861 A.D.

It is interesting to note that only the scientific and philosophical books were selected for translation, and not history, drama or poetry. Centuries later, when Europe tapped this source of learning, which was preserved in Arabic, they got a lot of scientific and philosophical writings of all the previous civilisations. The social sciences and humanities were, however, to be rediscovered by Europe directly from Greek and Latin. Thus, science and humanities entered into the modern tradition by separate channels. This, perhaps, explains to some extent the persisting divide between these areas of knowledge.

One of the reasons which ensured the growth of Arabic science, apart from flourishing trade by land and sea, was the fact that it was practised in a language used by the kings and slaves alike. This provided strong links between ordinary craftsmen and scholars, links which never fail to provide a great impetus to the growth of science.

The Arab science provided a genuine continuity to classical Greek science, and was also a melting pot for scientific thought of other civilisations. Yet, it seems to have had little ambition to improve upon or revolutionise these traditions. In studying Arab scientific works, we are struck by the rationality of treatment generally associated with modern science. However, mysticism and too much respect for Greek science and its leading figures like Aristotle became a handicap. The main pillars of science were astronomy and medicine. These were united by astrology which furnished the link between the outer big world of the heavens and inner small world of men. We would, however, like to state categorically at this stage, that the greatest figures of Arab science such as al-Kindi, al-Razi (Rhazes), Ibn Sina (Avicenna) and al-Biruni clearly rejected the extravagant claims of astrology and alchemy.

We have described above some general features of Arab science. You may like to work out an SAQ based on these!

SAQ 1

Which among the various factors given in column 2 helped or impeded the growth of Arab science? Indicate by drawing a line between the statements that correspond to each other in columns 1 and 2.

1	2
	i) The Arabs were willing to assimilate the best scientific traditions of classical cultures of Greece, India and China.
a) Features that helped the growth of Arab science.	ii) They had too much respect for Greek works.
	iii) The Arabs travelled extensively to various countries and brought back immense information.
b) Impediments to the growth of Arab science.	iv) Arab science was practised in a language used by kings and slaves alike.
	v) They could not completely escape from the influence of astrology, alchemy and mysticism.
	vi) The Arab treatment of scientific ideas is very rational.

We will now briefly describe the significant contributions of Arabs in some areas of science such as astronomy, mathematics, medicine, optics and chemistry.

Astronomy and Mathematics

Arabs carried on the Greek tradition in astronomy. They translated Ptolemy's Almagest and continued astronomical observations in spite of occasional religious interference. Although they did not add substantially to the Greek methods, the continuity that they provided was to prove invaluable to the sixteenth century astronomers.

The practice of astronomy provided the necessary incentive to develop mathematics. In this, the Arabs adopted the Indian system of numbers and introduced them on a large scal to the extent that warehouse clerks and traders started using these numerals to conduct the business. The widespread use of the number system simplified calculations and had the same effect on mathematics as alphabets had on writing. Arabs translated Indian works on algebra and trigonometry and applied them to solve many physical and practical problems

Geography

We have seen that Arabs were great travellers. Arab scholars travelled as far as Russia, Centra Africa, India and China. They wrote well-ordered and rational accounts of their journeys and made maps and charts. Their geography was not only descriptive, they also had some idea of the size and scale. In this way, they laid the foundation of modern geography of Asia and northern Africa (Fig. 5.2).

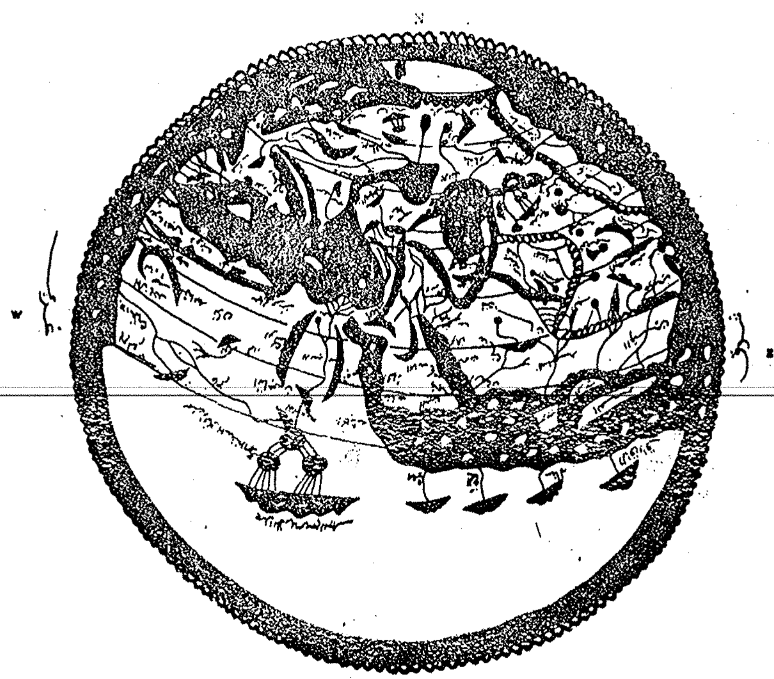


Fig. 5.2: Arabic map of the world.

Scientific Chemistry

The Arab doctors, perfumers and metallurgists made their greatest contribution in chemistry. This was mainly due to the fact that Arab scholars, unlike their predecessors in Greece, never hesitated to take part in laboratory practices in handling drugs, salts and precious metals. The Arabs continued the Egyptian and Babylonian traditions, and learnt extensively from the Indian and the Chinese sources. To these they added their own rich contributions, giving rise to the first statements of scientific chemistry.

Arab chemists greatly improved the earlier distillation apparatus and used it for large scale production of perfume. They also undertook large scale production of soda, alum, copperas (iron sulphate), nitre and other salts which could be exported and used particularly in textile industry. While they perfected new techniques, they were not satisfied till they were able to get at the bottom of the reactions which made these techniques possible. Arab chemists stipulated the positive and negative nature of two reacting constituents. This was the first time that chemical transformation was approached rationally, to lay the basis for modern chemistry.

Medicine

The Arabs continued the Greek tradition in medicine also, but added to it the knowledge of new diseases and drugs which was made possible by the wide geographical spread of Islam. The doctors, who were not only Muslim, but also Jewish, studied a great range of diseases. They concerned themselves with questions of the effect of climate, hygiene and diet on health. They also paid attention to the practical art of cookery.

Fig. 5.3 : Oldest representation of a caesarean section from the works of al-Biruni.

Optics

The prevalence of eye diseases in the desert and tropical countries led to the study of the eye by Arab doctors. Surgical treatment of the eye led to renewed interest in the structure of the eye. This was to give the Arab physicians the first real understanding of dioptrics, the part of optics dealing with the passage of light through transparent bodies like a lens or glass. This also laid the foundation of modern optics. The lens of the eye was to point the way to the use of crystal or glass lenses for magnification and reading, particularly by the old. The 'Optical Thesaurus' of Ibn al-Haitham (about 1038 A.D.) was the first serious scientific treatment of the subject.

SAQ 2

Which three among the following developments in science are contributions of the Arabs? Tick the appropriate statements.

a) The use of number system was greatly popularised.
b) Gunpowder was discovered.
c) Chemistry was treated rationally for the first time, large scale production of salts was undertaken.
d) A heliocentric model of the solar system was given.
e) The first scientific treatment of optics was carried out.

The bare outline of the developments in Arab science that we have given above is just a glimpse of its extent and importance. Arab scholars rescued Greek science from the decadent state it had fallen into under the later Roman Empire. They created a live and growing science. They were able to extend the narrow basis of Greek mathematical, astronomical and medical science by drawing on the experience of Persia, India and China. They also extended the techniques of algebra and trigonometry and laid the foundations of optics and scientific chemistry. These developments continued till eleventh century A.D., after which we find that the best days of Arab science were over. There were brilliant individual scientists like Averroes (about 12th century A.D.) and Ibn Khaldûn (about 14th century A.D.). However, the widely based and living movement existed no more. We will now try to analyse the reasons that led to the decay of Arab culture and, as a consequence, of Arab science.

5.2.2 Decay of Arab Culture and Science

The association of science with kings, wealthy merchants and nobles which was initially very fruitful, ultimately proved to be the weakness of Arab culture and science. The patronage provided opportunities to translate, observe, experiment and reflect upon various aspects of science. It also resulted in Arab science getting cut off from the people, who began to suspect that the learned advisors of the elite were upto no good. This made the common people an easy prey to religious fanaticism. The link also tied up the fortunes of science with the strength of the kingdoms. After the eleventh century A.D., both the Byzantine and Islamic empires (see Fig. 5.1) started breaking up internally and grew more dependent for military and economic purposes on local kings. By the time of the Crusades (between eleventh to thirteenth century), the empires broke up into local feudal estates where peasants and craftsmen were subjugated with renewed brutality. This destroyed the market for industry and the need for innovative science. In this situation of decay and stagnation came new barbarians from the steppe lands. They over-ran the Arab lands and effectively stifled their culture.

As a result of the regeneration of the Church and intensified internal religiosity, seven Crusades took place under the leadership of various European kings to subjugate other rulers and to extend the influence of Christianity.

The genius of Arab science lay in the fact that it provided a crucial link between the rise of modern science, and developments in Greece, in India and, to a lesser extent, in China in the classical period. Modern science, as we know it, arose in the sixteenth century after the Renaissance in Europe. The Renaissance took up the classical science as it was transmitted by the Arabs and developed it in a revolutionary sense. Thus started a new age in which science and technology could play pre-eminent roles, roles they had never been called upon to play before. We shall tell you more about this in Unit 6.

5.3 SCIENCE AND TECHNOLOGY IN MEDIEVAL INDIA

Let us now turn our attention to what was happening in India in the medieval times. As you have read earlier in Sec. 5.2.1, al-Biruni (973-1048 A.D.) had visited India and travelled extensively. He had studied the social life, political system and religious beliefs of the Indian people in depth. We get a great deal of information about India from his writings. In his writings he gave a detailed account of the level of scientific developments in India, in the early decades of the eleventh century A.D. His works also include reference to the earlier advances

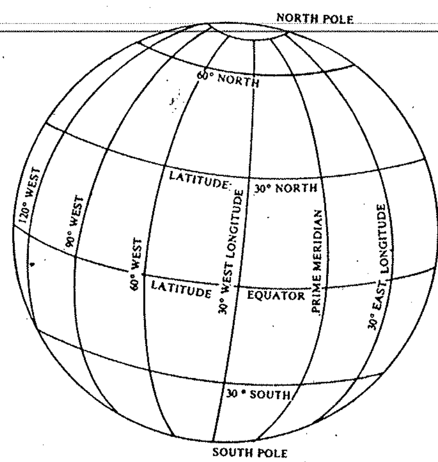


Fig. 5.4: A meridian is an imaginary circle passing through the poles of the earth, which divides the sphere into two equal parts. Twelve equally spaced meridians divide the earth into 24 equal sectors, each passing through the poles and each making an angle of 15° with its neighbour. By international agreement, the first or the prime meridian passes through Greenwich, England. The smaller of the two angles formed by the prime meridian and the meridian passing through any point on the earth is called the longitude of that point. The longitude of any point on the globe is measured east or west from Greenwich whichever makes the smaller angle. The parallels of latitude are lines drawn on the globe parallel to the equator. The latitude gives the angle north or south from the equator. The location of any point on the earth is described by its longitude and latitude.

in Indian science. For instance, he records the Indian contribution to astronomy and refers to the works of Aryabhatta, Varahamihira and Brahmagupta about which you have read in Unit 4. According to al-Biruni, Indians had tried to calculate latitudes (Fig. 5.4) of some places like Kannauj, Thanesar and Srinagar (in Kashmir). The calculation of longitudes was based on timings of the eclipse at different places, as had been suggested by Ptolemy earlier. Their prime meridian passed through Ujjain.

Al-Biruni points out that the Indian views regarding matter were similar to those of the Greeks. You have read about this in Sec 3.4 of Block 1. According to al-Biruni, the greatest Indian contribution was in the use of the decimal system. The numeral signs that the Indians used were the source of Arabic and the present day international numerals.

Al-Biruni's account is not a mere description of things as they were. He also tried to analyse why things were as they were. He realised that Indian science was already on the decline and lamented that "it is quite impossible that a new science or any new kind of research should arise in our days. What we have of sciences is nothing but the scanty remains of bygone better days". He attributed this situation to the lack of patronage to the scholars. This, incidentally, highlights the very elitist character of Indian science. It was restricted to a few people who practised science only as an intellectual exercise. Science in India had lost its connection with the life of common people or productive processes. There was, however, some change in the state of affairs with the coming of Islam to India.

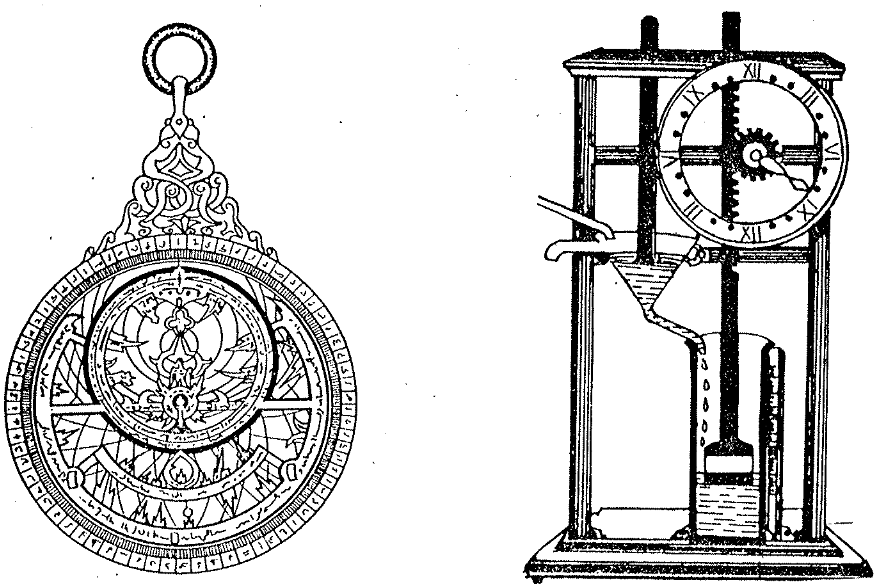
Islam came to India at a time when the vigorous intellectual phase of the Islamic civilisation was largely over. With al-Ghazzali's mysticism, a stiff resistance to rational philosophy had developed. Nevertheless, the Arab body of knowledge had inherited the best of sciences from the Greek civilisation, from China and from India. It also included innovations from within the widespread Arab civilisation. This entire body of knowledge became an Indian possession, all the more so as Indian scholars learnt Persian and Arabic after the establishment of the Delhi Sultanate. This influenced to a great extent the development of science in medieval India.

5.3.1 Achievements in Science

The interaction between Indian sciences and those brought by the newcomers remained limited for some time. However, astronomy and medicine received ready patronage from the Delhi Sultans as well as from Mughal Emperors and their nobility. We shall now tell you about the achievements in various areas of science in medieval India.

Astronomy and Physical Sciences

Astronomy was used not only for working out the calendar, the dates of the eclipses and for the determination of time but also for casting horoscopes for astrological purposes. Astronomy was also needed for fixing the direction of Mecca, in order to properly align the mosques. We find that Firozeshah Tughlaq (1351-88) established an observatory where a special type of astrolabe and water-clock were set up (Fig. 5.5). The interest of the rulers in astronomy continued during the Mughal period. Humayun is reputed to have employed a number of astronomers and with their help, he attempted to make astronomical observations.



(a) (b)

Fig. 5.5: (a) Astrolabe : front surface showing the graduated rim of a spherical astrolabe which is a small portable metal disc with a diameter varying from 4" to 8"; (b) water clock: as water flows into the cylinder, the float rises, turning the pointer on the dial to tell time.

The two systems continued to coexist but probably without any great interaction. Both hakims and vaids were employed by the Emperor and the nobles. In the list of physicians at Akbar's court one finds four vaids, i.e. practitioners of Ayurveda.

In surgery, blood letting, and in orthopaedics, setting right dislocated bones were the known practices. A practice attributed to the surgeons of Kangra was that of treating those whose noses had been cut. They could create an artificial nose by a partial skin transplant. However, unlike in contemporary Renaissance Europe, no important systematic researches in the field of anatomy or physiology were made. Observations, such as plague spreading through rats, were chance observations. An interesting technique, which was pursued by popular practitioners, was smallpox inoculation, since the disease seems to have spread silently all over West Asia and India in the seventeenth-eighteenth centuries. The practice, however, was not safe.

Europeans were also employed as physicians by Mughal nobility but the attempt to make use of their knowledge remained confined to individuals. For example, Danishmand Khan (a Mughal noble about 1660 A.D.) tried to understand Harvey's discovery of blood circulation from the French traveller Bernier who dissected a sheep for demonstration. But such display of interest in European medicine on the part of Indian scholars was exceptional, and even the translations of European scientific works prepared on the orders of Danishmand have not survived.

On the whole, we find that the development of science in medieval India was at a rather slow pace. There was no adequate response to advances in science made in Europe. The lack of endeavour to understand European science is evident from the fact that an Atlas presented to Jahangir by Thomas Roe was returned to him because Jahangir's scholars were unable to understand it. It is difficult to explain this failure when the European merchants, priests, travellers and physicians were found in most parts of the country.

One possible factor could be the narrow social base of learning, i.e. learning was restricted to a small elite group. This was to some extent due to the absence of printing. Printing was introduced in India by the Portuguese. However, the products of their printing press were not aesthetic enough to be appreciated by the Mughal court and nobility. The possession of books was a privilege of the rich. Thus, the spread of knowledge was prevented.

SAQ 3

In the space given below, list at least five significant developments in science in medieval India, one each from the fields of astronomy, geography, physics, chemistry and medicine.

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So far, we have told you about the developments in science. Let us now see what technical innovations and inventions were taking place in medieval India.

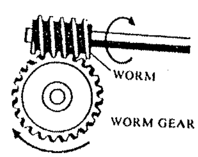


Fig. 5.8: The worm gearing has a short revolving screw (the worm) whose teeth move into the special teeth of a helical gear (the worm gear).

5.3.2 Technical Innovations and Inventions

Medieval India witnessed considerable improvement and changes in the field of technology. While these changes were largely a result of diffusion from outside, some technological innovations also originated in India. Diffusion from outside suggests readiness and ability to imitate, apply and extend the use of technological devices. On the whole, there seems to have been no inhibition against technological change.

We shall now describe some technical devices that were invented or improved upon in medieval India.

Gearing

Gearing provides a device for transforming horizontal motion into vertical and vice versa and for increasing or reducing speed (Fig. 5.8). One form of gearing is that of the parallel worm which originated in ancient India. It was received in Kampuchea, in all probability, from India before 1000 A.D. Parallel worm gearing was used in wooden cotton-gin in medieval times; it was also applied to sugar milling, with wooden rollers.

Right-angled pin-drum gearing came with the Persian wheel (*saqiya*), an improved water lifting device received from the Arab world. India already had water lifting devices such as pulley-system (*ghirni*) and noria (*araghatta*) with pot-chain (*mala*). The application of pin-drum gearing to the *araghatta,* converting it into what is known as the Persian wheel, enabled water to be lifted from deeper levels, in a continuous flow, by use of cattle power. The gear wheel and the shaft were of wood. A horizontal pin-drum, meshing with a vertical pin wheel, was rotated by cattle power. The Persian wheel was being widely used in the Punjab and Sind by the fifteenth century. This improved the means of irrigation and probably resulted in extension of agriculture in the region.

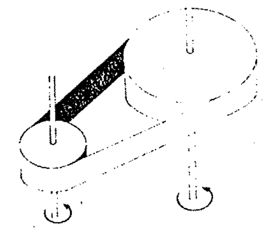


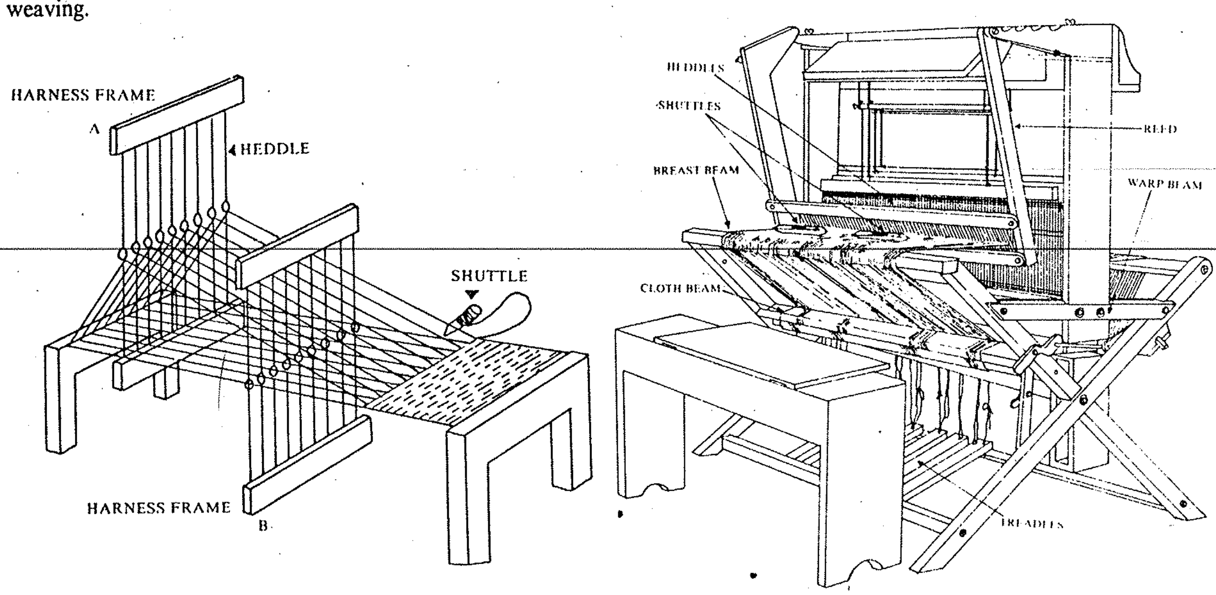
Fig. 5.9: Belt drive found in the charkha, home sewing machine and the fan of an automobile engine.

Belt-drive

The belt-drive is a comparatively simpler device than gearing for transmission of power and for increasing or decreasing the speed of motion (Fig. 5.9). Belt-drive came to India in the form of the spinning wheel. The spinning wheel quickened the speed of spinning by about six fold. This must have resulted in reducing the prices of yarn and, thus, of cloth. The other improvement in the spinning wheel was the addition of crank handle during the seventeenth century. The belt-drive was extended to the diamond cutting drill, by the seventeenth century.

Weaving

Evidence of an improvement in weaving comes from a fifteenth century dictionary which describes the foot-pedals used by a weaver to control speed. The addition of treadles to the loom facilitated the use of feet by the weaver for lifting alternately the heddles and freed his hands to throw the shuttle to and fro (Fig. 5.10b). This could more than double the rate of weaving.



(a) (b)

Fig. 5.10: (a) A simple loom. Harness A is raised so that the shuttle goes under those warp threads, but over the warp in B. The harnesses are reversed and the shuttle is passed back under B and over A; (b) in the foot-operated handloom the warp threads are wound on a cylinder called the warp beam. Each thread passes through a heddle or vertical rod. Alternate heddles are separated so as to form two groups held together by harnesses. When one set of heddles is raised and the other is lowered, the warp is separated into two sections, forming a shed through which shuttle is passed. The position of heddles is reversed to form another shed and the shuttle is passed through again. The woven cloth is wound onto a cloth beam.

By the seventeenth century both methods of multi-colour pattern dyeing, namely, the use of resist to confine colours to patterns and of mordant to take colours were used. It was, perhaps, during the same century that direct block printing, a time-saving technique as compared to painting, became popular in India.

Paper manufacture

Paper was not used in India until the eleventh century. This Chinese invention of the first century A.D. reached India mainly through the Ghorian conquerors. Once introduced, its manufacture spread quickly, and by the middle of the fourteenth century, paper became so cheap that it was used not only for writing but also for wrapping purposes by the sweetmeat sellers.

Bridget and Raymond Allchin are archaeologists. Joseph Needham, a scientist, is well known for his works on the history of science and society in China.

Distillation

The know-how of liquor distillation also came to India during the thirteenth century. Though it has been argued by the famous Indian chemist P.C. Ray (1861-1944 A.D.) and recently by the Allchins and Needham on the basis of archaeological evidence, that liquor distillation was known in ancient India, the stills seem to have been small and inefficient. With the thirteenth century came various types of stills (for liquor as well as for rose-water) and there is little doubt that the manufacture of distilled spirits received great impetus.

Architecture

The architectural style of India underwent a drastic change after the Turkish conquest. The Sultans and their nobles insisted on having arches and domes and competent Indian masons succeeded in building them. The first surviving example of arch is Balban's tomb, dated 1280, and of dome, Alai Darwaza, dated 1305. It was the change in building technology accompanied by the introduction of lime mortar that made possible the change from trabeate architecture to arcuate style. The principle of true arch seems to have been known in ancient India, but somehow large arches could not be made. However, false arches were constructed in ancient times (see Fig. 5.11).

Use of lime mortar made it possible to waterproof floors and walls for tanks. Thus, it became possible to build tanks and vats such as those needed for producing India's major dye, indigo.

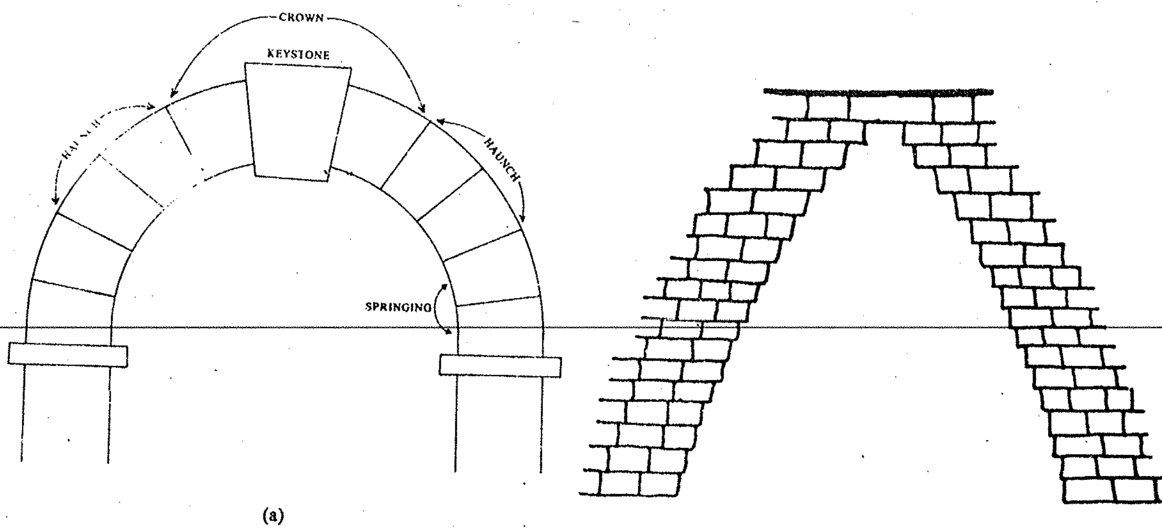


Fig. 5.11 : (a) True arch : its lower part is called springing, top is the crown, and shoulder is the haunch. Keystone has a key position in the formation of arch ; (b) false arch is built of horizontal layers so laid that each projects slightly beyond the one below, gradually coming together at the top where the meeting point is covered by a flat slab.

Military Technology

Important changes were introduced in military technology. Rope and wooden stirrups for horsemen were known in India before the thirteenth century. However, the iron stirrup seems to have been introduced by the Ghorians and the Turks. This greatly improved the combat power of horsemen. At the same time, shoeing improved the performance of horses.

Turks also brought with them the cross-bow (Fig. 5.12). The cross-bow had an additional tube at right angles to the bow in which the arrow was fitted; the tube gave greater accuracy of direction to the arrow. This tube seems to be a direct precursor of the barrel of the hand-gun.

The next stage of development in military technology was the use of cannon and gun powder. This innovation came to India during the latter half of the fifteenth century from the Ottoman Empire which had itself received it from Europe.

By Akbar's time, match-locks and their manufacture became common in the imperial arsenal. Some improvements were attempted mainly with a view to do away with the match and strengthen the barrel. Akbar's arsenal succeeded in manufacturing a gun that had most probably a wheel-lock. Here the spring released by trigger caused a wheel with serrated edges to revolve against a piece of pyrites and so send sparks into the priming pan. The flintlock widely used in Europe by the first half of the seventeenth century was adopted in India later on (Fig. 5.13).

Manufacture of the barrel of a gun posed a problem for the gunsmith. The barrel had to be very strong to withstand the explosion within it; the making of the bore and alignment required high accuracy. In Akbar's arsenal, the barrel was made by rolling flat iron sheets and welding the edge. Thereafter, the bore was worked from inside. The same technique was used in Europe down to the eighteenth century.

India was credited with casting the heaviest bronze cannons in the world at the close of the sixteenth century. But the heavy guns were not necessarily efficient as they lacked mobility as well as accuracy. We find that Akbar paid great attention to the manufacture of lighter guns that could be pulled by a single man.

An important device used in the Indian army was *bana* or rocket. This was made of bamboo, with iron cylinders containing combustible materials at the tip. It was this Indian rocket that inspired the invention of rockets by Congreve in early nineteenth century.

Metal Screw

One important device that had a great potential in the manufacture of precision instruments and machinery was the metal screw. It came into use in Europe from the middle of the fifteenth century for holding metal pieces together. Its use was of great importance in mechanical clocks. The screw began to be used in India by the second half of the seventeenth century and even then it was a less efficient version of the European screw. The grooves were not cut, but wires were soldered around the nail to create the semblance of grooves. This had to be done owing to the absence of lathes which were used in Europe for cutting grooves. Due to this limitation, the Indian screw did not fit properly.

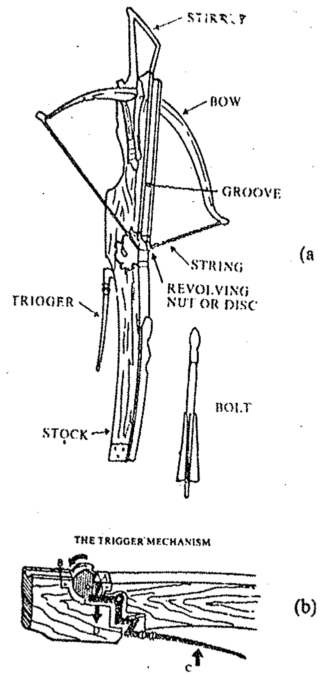


Fig. 5.12: (a) Cross-bow and (b) how it works. String of the bow is drawn back and held in a notch (A). Bolt, a type of arrow used with cross-bow is then laid in a groove on top of the stock (B). When the trigger is pressed upward (C), the rod drops, allowing the circular plate in which the string is resting to spin freely. Force of the released bowstring sends the bolt through the air with great force.

Ship-building

The ship-building industry in the seventeenth century witnessed far-reaching changes that mainly resulted from imitating European techniques. The Indian sea-going ships, until the first half of the seventeenth century, were called 'junks' by the Europeans. These were very large and supported immense main sails. In some ways, the imitations even improved upon the originals. The Indian method of riveting planks one to the other gave much greater strength than simple caulking used by European ship-builders. A lime compound dabbed on planks of Indian ships provided an extraordinarily firm protection against sea-weeds.

However, it was the instruments used on ship where India lagged much behind Europe. Indians failed to fashion modern navigation instruments. The main instrument used on Indian ships still remained the astrolabe. Later, in the seventeenth century, European captains and navigators were employed on Indian ships, and they naturally used telescopes, quadrants, and other instruments that were imported from Europe.

Agriculture

Agriculture has been India's largest industry. The Indian peasants have used seed drill from antiquity; in the seventeenth century they practised dibbling, that is, dropping of seeds into holes driven into the ground by sticks. They also practised crop rotation in most areas. The number of crops grown by Indian peasants was quite large. Abu'l Fazl mentions around 50 crops for *kharif* and 35 for *rabi* seasons, though their number varied from region to region. The most remarkable quality of the Indian peasant was his readiness to accept new crops. The new crops introduced in the seventeenth century that came from the New World were tobacco and maize. These crops came to be grown quite widely. By the fifteenth century, the peasants of Bengal also took up sericulture and by the seventeenth century, Bengal had emerged as one of the great silk exporting regions in the world.

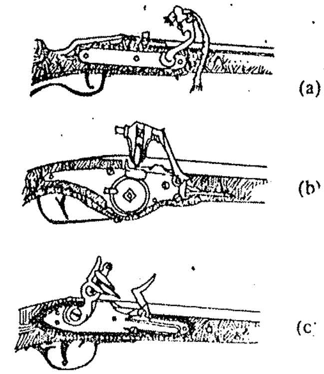


Fig. 5.13: Different firing mechanisms of guns in use in the medieval times; (a) match-lock: when the trigger was pulled, a curved hammer thrust the burning cord into the hole igniting the gunpowder; (b) wheel-lock: pulling the trigger released a clock-type, hand wound spring, which spun a steel wheel against a piece of flint or iron and gunpowder was ignited by a shower of sparks; (c) flint-lock: a simple spring snapped the hammer down when the trigger was pulled. A piece of flint or iron held in the hammer jaws created sparks igniting gunpowder

Horticulture developed considerably under aristocratic patronage. Various types of grafting were introduced. In Kashmir, sweet cherry was obtained by grafting, and the cultivation of apricot was also extended by the same means. During Shah Jahan's time, the quality of oranges was greatly improved by use of the same technique. On the western coast, the Portuguese introduced mango grafting and Alfonso was the first mango produced in this fashion. Mango grafting seems to have spread in northern India during the eighteenth century.

To sum up, in this section we have tried to give you a brief overview of the scientific and technological developments in India during the medieval times. If we look at the 600 years of development of science in medieval India, we cannot but be disappointed. There seems to have been progress here and there, in astronomy, medicine and technology, but all within the old frame of thought which is often called Aristotelian : a world which always was as it is now, and will continue to be so: a universe at the centre of which was the earth and all things were made of five elements—fire, air, water, earth and ether. The concept of master and slave of the Greek society or hierarchical structure was so natural that it also pervaded the physical world where everything knew its place and fulfilled its purpose.

There was, indeed, no effort to incorporate the latest findings in each subject, to even be aware of the discoveries being made in contemporary Europe. There was still less effort to develop a theoretical and philosophical understanding in which each element of knowledge could fit. Little interest was taken in such remarkable advances as Copernican model of the solar system, Galileo's work (1610), Newton's great work on gravitation (1665), or even circulation of blood discovered by Harvey (1628). The invention of the printing press which had the potential to make knowldege available to a larger number of people or again the telescope (about 1600) and the microscope attracted no attention. It is remarkable that the few centres of learning that existed propounded theology, either Hindu or Muslim, or explained a body of knowledge that already existed. Their role was not to break fresh ground and develop new things.

Why was it so? We shall now try to analyse why science and technology did not grow in India as in Europe in those times. But before reading further you may like to try an SAQ.

SAQ 4
List at least five technical innovations of medieval India in the space given below.

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5.4 IMPEDIMENTS TO THE GROWTH OF SCIENCE IN INDIA

By the end of the eighteenth century, Indian society had become very complex. Hence it is difficult to discuss even one aspect of it, that of science, as it arose from this society and contributed to it, without over-simplifying. However, if simplification makes sense and does not distort the picture, it is a good thing, because it gives us an overview which helps in understanding the interaction between science and society.

What may have struck you from the brief presentation given here is that Indian science was at the same level as science anywhere else in the world. In particular, it was at the same level as European science, upto about the middle of the sixteenth century. But, then European science took big strides forward and left Indian science way behind in the period that followed. In fact, the British were able to subjugate this country, and make it their colony, on the basis of science, technology and industry which had developed there. The question that naturally arises is what the difference between Europe of sixteenth century and India of that period was. If you get interested in pursuing the question, you would probably have to read history in depth. However, to put it simply, the difference in the two societies was in their social structure, in the degree of the hold of religious orthodoxy, and the intellectual atmosphere. Let us explain what we mean.

We have seen that one kind of pressure for advancing knowledge and technology comes from the necessity of satisfying human needs. There is an old saying that necessity is the mother of invention. Well, it appears that in spite of periodic wars between the rulers of various regions and states in the country, there was a very considerable stability in Indian society. Population was small, the land was fertile and even from small land holdings Indian peasants were able to meet the requirements of subsistence. They could feed and clothe themselves. Although there were poor people, poverty and hunger of the kind we see today did not exist. The deprivation that we see today is largely a result of British policies imposed on us. The hold of religion, particularly in the rural areas, and the existence of the caste system, contributed both to a certain reconciliation with fate, and an acceptance of the social hierarchy. There was a fascination with the idea of an infinitely old universe condemned to an endless cycle of deaths and rebirths, in which nothing fundamentally new could ever happen. What can be called a peculiar kind of satisfaction prevailed, which did not allow pressures to build up for either enhancing production through technological innovation, or to change the society.

Another reason was that those who worked with their hands did not contribute to the stock of knowledge. And those who possessed even out-dated knowledge never had to test it on the touchstone of practice. Either the kingdoms fought wars or settled down to long periods of peace. It seems natural to think that in such a society there was no clamour to develop new products or new processes. Social stability and stagnation can easily go hand in hand. The rich had no need for change, the poor had no power to bring about change.

We have seen that when Islamic influence entered India in successive waves, it tended not to disturb the life of the common people who lived in rural communities. It did not interfere with the prevailing religious ethos, which remained predominantly Hindu, with its ideology tolerant of great variations, but at the same time protecting the caste system which was well established in India. We find that at the level of administering the country, and in the armed forces there was mutual support between the higher strata of people in the two communities. Muslim kings with Hindu Commanders-in-chief, and Hindu Rajas with Muslims at the head of their armies are known to have fought and also defended each other. Naturally, there was give and take, and intermingling of cultures. What we call Indian culture today is a result of centuries of interaction between our people of different areas and of those who came and settled down here in different periods.

At the level of religion, there was coexistence between Islam and Hinduism, perhaps, out of necessity, since the Muslims were in a small minority. They could certainly not afford a confrontation with the vast majority if their rule was to last in India and was to be extended in the centuries to come. This was also because priests had a great hold over people, and any interference in each other's affairs would have had serious political consequences. It could have led to turmoil. So, each steered clear of the other. Further, the priests of the two communities were well off, and satisfied with their economic condition. Within the two religious systems too, there were no active controversies and no strong movements of reform. The Bhakti and Sufi movements did arise in the medieval period. These movements preached religious tolerance and were highly critical of the caste system. However, they did not make a wide impact as their word did not reach far.

This was perhaps due to the absence of printing. Typically, when a printed book was presented to Jahangir, he is said to have thrown it away, saying that it was ugly and unaesthetic as compared to the beautiful calligraphy in which they prided. He little realised or was, perhaps, little interested in the possibility of enriching people's life on a large scale through the availability of cheaper books. This was in contrast to the sixteenth century Europe where the availability of printed word greatly helped the spread of knowledge that created a wider and deeper impact for bringing about social change. You will read more about this in Unit 6.

In India education was, by and large, limited to religious teaching and the intellectual atmosphere was not in favour of challenging the established ways of thinking, or of propounding new theories. In such an atmosphere few would venture to propose freedom of thought. It was still more difficult to accept such new things as a sun-centered universe demonstrated by Galileo. For, the new theory changed the order which was believed to have been established by God to give the abode of man a central position in the entire creation. Indeed, astrology was, perhaps, esteemed enough to let astronomy go on! Alchemy still held some promise of converting base metals to gold, howsoever mysteriously or irrationally, to allow dabbling in chemical techniques! The reign of the orthodoxy with its belief in eternal or revealed truths never allowed free thinking and imaginative adventure of ideas. To put it in another way, the learned had fixed ideas which they did not need to change. And those whose social status was low and who were exploited by the feudal order had no access to learning.

If it were not for these factors, we had a tremendous advantage over Europe in the sense that the strong streams of Arab and Indian science coexisted here, and we should have been miles ahead of Europe. In Europe, comprehensive books of Arab authors like *Compendium of*

Astronomy by al-Fargani, *Howi, Liber Continens* by al-Razi, the *Canon* of Ibn Sina and the *Colliget* of Averroes (all medical treatises) were used as text books in the seventeenth century. All these books were available in India and could have been used, but were not. The exciting advances made in science during the sixteenth and the seventeenth centuries in Europe, such as the works of Copernicus, Galileo and even Newton did not attract widespread attention, since they were not close to the hearts of such scholarship as existed in India at that time. Due to this indifference and neglect and the other factors mentioned earlier, we lost the race.

All this can, perhaps, be summarised by saying that a traditional, hierarchical society with a low level of discontent and conservatism promoted by both the religions, made scientific advance superfluous. Naturally, such a society could not bring about a scientific revolution such as was taking place in contemporary Europe in the sixteenth and the seventeenth centuries. It could, and did, devote its attention to the good things of life such as drama and music, dance and painting, architecture and poetry. This, at least, was the saving grace of the medieval society.

5.5 SUMMARY

In this unit we have covered a long period in history starting from about the seventh century A.D. to about the eighteenth century A.D. Geographically also, we have covered a wide region spread from the West Asia where Arab science flourished, to the Indian subcontinent. We now summarise what we have learnt.

- We have seen that Arab science provided continuity between the classical science of the Greek, Indian and Chinese civilisations and science in the medieval times. For the first time a rational approach was adopted by the Arabs in the study of many areas of science as applied to the solution of practical problems. Arab scientists were from the common people, spoke the same language and shared common problems. This gave an impetus to the growth of practical science. We have also seen that about the eleventh century A.D., the vigorous intellectual phase of Arab science faded out due to several reasons.
- Medieval India had the advantage of having a vast storehouse of knowledge which was gained through contact with the Arabs and the Europeans. The Indian people were able to pick up the technical innovations. Many innovations were also made here. However, they failed to imbibe the raticnal philosophy of the Arabs or appreciate the scientific endeavour taking place in contemporary Europe. The reasons for this attitude may be seen in the prevailing social conditions. This resulted in Indian science being left far behind.

5.6 TERMINAL QUESTIONS

1) Explain in four or five lines how the absence of printing hampered the growth of science in medieval India.

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2) Which three among the social factors mentioned below became impediments to the growth of science in India in the medieval times? Tick the correct choices.

   a) There was stability in society. There were no pressing socio-economic needs to demand scientific innovations. ☐

   b) Art and music, drama and painting thrived. ☐

c) The hold of Hindu and Muslim religions on their adherents was absolute. The reformist movements created very little impact. ☐

d) The intellectuals in the society had fixed ideas that need not have been tested with practice. The peasants and artisans had no access to learning. ☐

e) Mughals made great contributions to architecture. ☐

3) State, in the space provided alongside, whether the following statements about science in medieval times are true or false?

a) Medieval times signify the darkest period in the growth of science in India. ☐

b) Indian scholars of the medieval period did not show much interest in disseminating knowledge by using comprehensive text books on astronomy, medicine etc. ☐

c) The availability of printed works of learned men played a great role in bringing about change in the European society. ☐

d) Indian science was linked with the lives of common people and the productive processes. ☐

e) The Indian people showed remarkable willingness to imitate and extend the use of technology obtained from contact with Europeans. ☐

5.7 ANSWERS

Self Assessment Questions

1) a) (i), (iii), (iv), (vi).
   b) (ii), (v).

2) a), c), e).

3) i) The establishment of observatories by Raja Jai Singh.
   ii) The preparation of a World Atlas by Sadiq Isfahani.
   iii) The measurement of specific gravity of metals, stones, wood etc.
   iv) The discovery of freezing mixture.
   v) Creation of an artificial nose by partial skin transplant; the practice of smallpox inoculation.

4) Persian wheel, rocket, iron stirrup, light guns, ships with riveted planks, astrolabe, grafting.

Terminal Questions

1) The absence of printing meant that learning was restricted to a small elite group. The practitioners could not have access to books. Thus, the gap between theory and practice could not be bridged. You can further expand this answer.

2) a), c), d).

3) a) F b) T c) T d) F e) T.

UNIT 6 RENAISSANCE, THE INDUSTRIAL REVOLUTION AND AFTER

Structure

6.1 INTRODUCTION

In Unit 5 we have described the scientific and cultural developments that took place in the Arab world and in India during the medieval period. We are now going to describe, in brief, the European society of those times. You have read about the Iron Age Greek and Roman societies in Unit 3. You also know that these Iron Age societies were slave societies.

The slave economy of classical times was followed by a feudal system which lasted well into the seventeenth century. The feudal system was technically and economically more fragmented than the slave society which it replaced. It did not contribute much to scientific thought. However, several new productive techniques were introduced on a small scale. These techniques were used by common people and were, therefore, widespread. In this unit we will describe these techniques in brief. As we will see, this, along with the accompanying economic changes, laid the basis for the transformation of feudalism to capitalism and the birth of modern science in Europe.

In Unit 5 we had tried to analyse why science did not flourish in India, the way it did in Europe from the sixteenth century onwards. In this unit we will complete the analysis by outlining the features of European society that helped the growth of science there. We will, once again, cover a long period in the history of science, picking up the thread from the fifth century A.D. We will dwell briefly on the feudal system which contained the seeds of the transition to capitalism, and then describe the Renaissance and the Scientific and the Industrial Revolution, which led to the emergence of modern science. If you want to go into the details of the social conditions prevailing in the European society, you may refer to Units 7, 8, 9 of the Foundation Course in Humanities and Social Sciences.

We also find that the Industrial Revolution created a great demand for raw materials as well as for markets to sell goods. This led to the colonisation of many backward countries, including India, by the newly industrialised countries. In the next unit we will discuss the developments in science and technology in India during the colonial rule and the post-Independence period.

Objectives

After studying this unit you should be able to :

- describe the developments in science and techniques in the European society during feudal times and explain how these led to the transformation of the feudal society,
- describe the social changes brought about by the Renaissance and the consequent developments in science and technology,
- outline the important scientific developments in the post-Renaissance period,
- compare the Indian and European societies of the period from the sixteenth to the

eighteenth century and analyse the features of the then European society that helped the birth of modern science,

- describe the technical innovations leading to the Industrial Revolution, its consequences and some of the major scientific advances made thereafter.

6.2 SCIENCE AND TECHNIQUE IN MEDIEVAL EUROPE

About the second century A.D., the collapse of the Roman Empire and the barbarian invasions by Franks, Goths, Magyars, Vandals, Slavs and others brought about conditions in Europe, in which the slaves could revolt and free themselves. But even in freedom, slaves could not do much since they had no land to produce food for themselves. Though the Romans had conquered the whole of Western Europe and had come as far as England (see Fig. 3.18), agricultural land was limited. Most areas in western Europe were covered with thick forests and even the soil was clayey and heavy. The Romans did not have the agricultural tools and techniques for working such land for cultivation. This led to widespread scarcities of food and other daily necessities, which resulted in discontent. In other words, the breaking up of slave society was accelerated by its own tensions and scarcities. We find that from the fifth century onwards, slaves were disappearing and their place was being taken by serfs.

Towards the beginning of the tenth century, a new productive system and a new society had established itself in many parts of Europe. This was the feudal system. Let us now see what this society was like and the status of scientific and technological development in it.

6.2.1 The Feudal Society

The economic basis of the feudal system was land, and the village was its economic unit. The feudal economy was dependent on local agricultural production and a scattered handicraft industry. In the villages, peasants or serfs shared the land and work. But they were forced to yield part of the produce or labour to their lords in the form of rent, taxes or feudal service. Usually, a lord owned one or more villages or land in several villages. The serfs were obliged to maintain their lords and they were not allowed to leave the land on which they worked.

This obligation of feudal service, that is, of work exacted by force or by custom backed by force, is the characteristic of the feudal system. What distinguished the serfs from the slaves of classical times is that unlike the latter who were owned by the slaveowners, the former were free men and had a secure tenure to cultivate land. Though the serfs were nominally free, their condition was not much better than that of slaves. However, social pressures on them had been somewhat reduced. This feudal order lasted until about the seventeenth century in Europe.

The period from the tenth century to about the fifteenth century is usually called the Middle Ages in Europe. In this period, the Church was the centre of power. It provided a common basis of authority for all Christendom. It was also an instrument for intellectual expression. All intellectual activity was carried on by people who were part of the Church. Thus, the Church dominated all walks of life. Therefore, the clergy had to be trained to think and write, in order that they may be able to defend the faith and take up missionary work. At first, this need was met by setting up cathedral schools. By the twelfth century, these had grown into universities. The first university to come up in this period was at Paris, in France, in 1160. It was followed by the founding of Oxford University in 1167 and Cambridge University in 1209 in Britain. Then came the universities in Padua (1222), and Naples (1224) in Italy, Prague (1347) in Czechoslovakia, and several others. These universities were mainly for training the clergy.

Teaching in these institutions had to be only by lectures and debates because books were still rare. The curriculum comprised grammar, rhetoric, logic, arithmetic, geometry, astronomy, music, philosophy and theology. In practice, the amount of science that was taught was very little. Arithmetic dealt with only numbers, geometry with the first three books of Euclid and astronomy got no further than the calendar and how to compute the date of Easter. There was little contact with the world of Nature or the practical arts, but, at least, a love of knowledge and an interest in argument was fostered. As we know, education by itself can be a positive factor in human development. In this case religious personnel were being trained according to a specific curriculum, and the universities were citadels of conservatism. However, they did

Easter is a Christian Festival commemorating the rising of Jesus Christ from his grave. It falls on a Sunday but the date may change every year.

come in contact with the creative thought of others, particularly the classical Greek thought and, to some extent, Arab, Indian and Chinese thought. This led to an intellectual climate which proved good for the future developments and discoveries in science.

But in the Middle Ages, education was still restricted to a small number of people. What may be called 'scientific' investigation was undertaken only by the clergy. And it was done to somehow justify religious beliefs. There was a constant debate between faith and reason, but even reason was used to prove the supremacy of divine thinking, revelation and every aspect of Christian dogma. We will now describe very briefly the 'scientific achievements' of the Middle Ages.

Medieval Science

We can record the sum total of the medieval achievement in the natural sciences in a few lines. It can be put down as a few notes on natural history and minerals, a treatise on sporting birds, such as falcons, hawks etc., some improvements in Ibn al-Haitham's optics and some criticism of Aristotle's ideas. In mathematics and astronomy, the Arabic algebra and Indian numerals were introduced and Ptolemy's Almagest was translated. The medieval European astronomers could not go much beyond the Arab contribution in observational astronomy although they added a few details. They made some contribution to trigonometry and the construction of instruments. However, there was no radical revision of astronomy. Robert Grosseteste (1168-1253), a Bishop and Chancellor of Oxford University, was a leading scientist of the Middle Ages. He thought of science as a means of illustrating theological truths. He experimented with light and thought of it as divine illumination. There were many other such 'scientists' in the Middle Ages.

Those who questioned the prevalent religious beliefs, were likely to be prosecuted for heresy! Even the idea that man could reach God directly without intermediaries, such as priests, was considered a heresy. The Middle Ages were an era of faith and of regimented thinking. The feudal society in its social, economic and intellectual character was again a stagnant society. The limited contribution of medieval science under such conditions is understandable. It is, indeed, unfair to expect more of such a science than what was demanded from it in its time!

However, the feudal society was definitely on a higher technical level than the slave society of the Iron Age. In fact, the impetus to technical innovations had existed from the beginning of the Middle Ages. This arose from the need for better use of land. It was here that the peasant and the workman could use and improve the classical techniques. For most of the Middle Ages there was a chronic labour shortage with the labour force of slaves no longer available and with the expansion of cultivable land in the countryside. Thus, human labour was sought to be substituted by mechanical means; manpower shortage led to the use of animal, wind and water-power. Thus, we find that many technical developments took place in medieval Europe though most of them seem to have come from the East, especially from China. Let us see what these developments were. But how about trying an SAQ first!

SAQ 1

Which factors among the following led to technical developments and which ones were responsible for very little advances in science in the European society in the Middle Ages? Put a 'T' for the former and an 'S' for the latter against each statement.

i) Expansion of cultivable land. ☐

ii) Only priests conducted scientific investigations to justify religious beliefs. ☐

iii) Shortage of labour due to absence of slaves. ☐

iv) A need for better use of land by serfs. ☐

v) To question religious beliefs or say anything contrary was branded a heresy. ☐

Technical Developments in Feudal Society

Major inventions, namely, the horse collar, the clock, the compass, gunpowder, paper and printing, were not developed in feudal Europe. Most of these were being used in China during the first few centuries of Christian era. We need to know about these advances because, in Europe, the use of some of these techniques set in motion a revolution, which contributed to the breakdown of the feudal system.

The horse collar and the **mills** were more efficient means of using power. The horse collar originated in seventh-century China and reached Europe in the eleventh century. Its use resulted in a manifold increase in the horse's ability to pull loads and work longer. Horses took the place of oxen at the plough and more acres of land could be cultivated (Fig. 6.1).

(a)

(b)

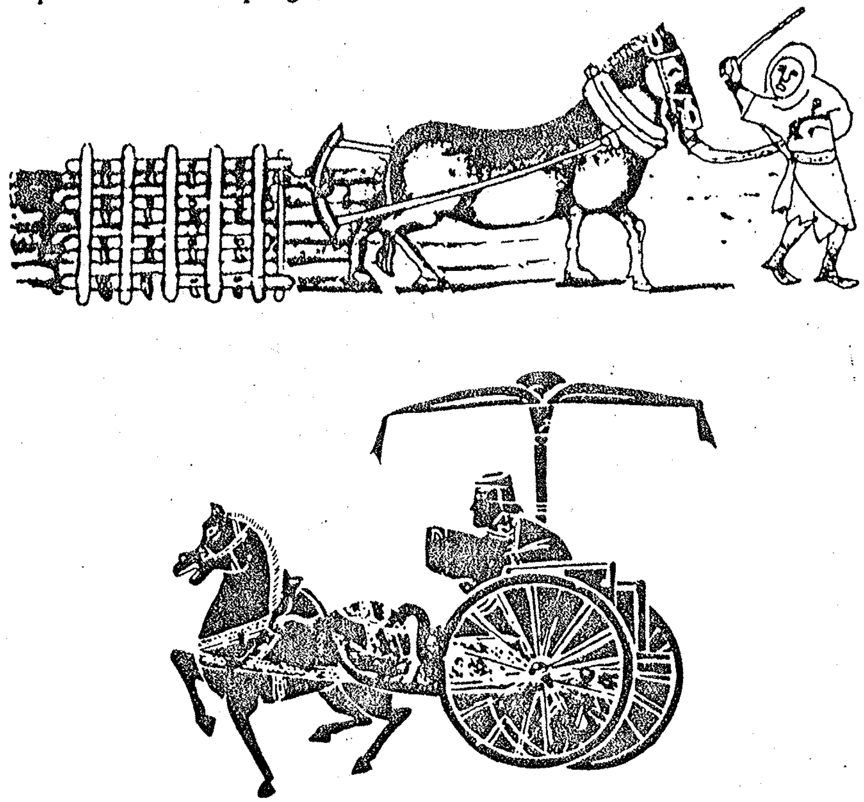

Fig. 6.1: (a) Horse collar in use in the fourteenth century in England; (b) improved horse collar that made a great difference to the load that a horse could draw.

The **water-mills** were also invented in the classical period. But they came to be widely used only in the Middle Ages. The **wind-mills** and **water-mills** harnessed nature for performing mechanical work. These mills were used for grinding grains, extracting oil from seeds and drawing water from wells, thus helping agriculture. They were also used for blowing bellows, forging iron or sawing wood. Mills became so popular that a mill and a miller were found in every lord's domain. The task of making and servicing the wind and water-mills was beyond the skill of most village smiths. Therefore, there grew a trade of mill-wrights who went about the country, making and mending mills. These men were the first mechanics who knew all about the making and working of gears. They also had a hand in the development of mechanical clocks and watches.

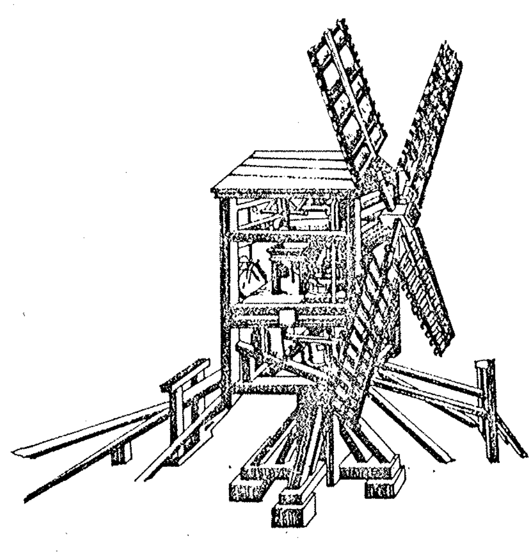

Fig. 6.2: Wind-mill.

There were two navigational inventions, the compass and the sternpost rudder, that had a profound impact on sea voyages in the Middle Ages (Fig. 6.3). The earlier sea trade routes were along the coastline of various countries (see Fig. 4.11 in Unit 4). With these two inventions, the oceans were thrown open to trade, exploration, and even war for the first time. Open-sea navigation required accurate charts of the position of stars, latitudes etc. and gave an impetus to later developments in astronomy and geography. It also raised the urgent problem of finding the longitude. The need for compasses and other navigation instruments brought into being a new skilled industry.

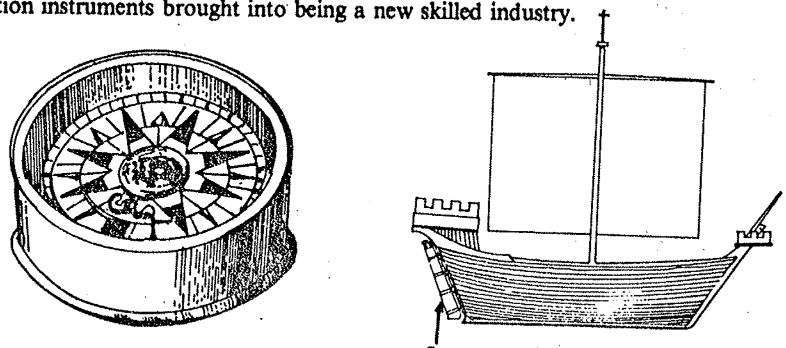

Fig. 6.3 : (a) Mariner's compass; (b) thirteenth century boat showing a rudder in the stern.

Other innovations used and improved by the Europeans were the **lenses** and the **spectacles.** This gave an impetus to the further study of optics and there were some contributions to Ibn al-Haitham's optics, as mentioned earlier. The demand for spectacles also gave rise to the profession of lens grinders and spectacle makers.

Distillation of perfumes and oils was already known in Europe through the Arabs. To this was added the **distillation of alcohol**, which gave rise to the first scientific industry, that of distillers, and laid the foundation of modern chemical industry.

Of all the innovations introduced in the West from the East, **gunpowder** had the greatest effect politically, economically and scientifically. With its use in cannons and hand guns, gunpowder enormously altered the balance of power. In science, the making of gunpowder, its explosion, the expulsion of the ball from the cannon and its subsequent flight, furnished many practical problems. Solutions to these problems and the accompanying explanations occupied the attention of medieval scientists for many centuries and led to sciences like mechanics and dynamics. The preparation of gunpowder required a careful separation and purification of nitre giving rise to the study of solutions and crystallisation. Nitre provides the oxygen needed for explosion of gunpowder. So, unlike ordinary fire, it does not require air. Studies related to the explosion of gunpowder led to attempts to explain combustion, i.e. burning. These attempts were later extended to studies on breathing which provides the oxygen needed to convert food into energy inside the animal body. These explanations were not easy at that time and taxed the ingenuity of medieval chemists most.

Two other technical introductions from the East had a far greater effect in the West than in the land of their origin. They were the inventions of **paper** and **printing**. The need for a writing material cheaper than parchment became urgent with the spread of literacy. Linen rags provided the basis for the first paper of quality. Paper turned out to be so good and cheap that its increased availability led to a shortage of copyists. This contributed a lot to the success of printing, originally a Chinese invention of the eleventh century.

Printing, with movable metal types, was first used by Koreans in the fourteenth century. It was introduced into Europe in the mid-fifteenth century and it spread rapidly, first for prayers and then for books. The new, cheap, printed books promoted reading and created increased access to education for a larger number of people. This, as we shall see, became a medium for great technical and scientific changes as well as changes in the society during the Renaissance.

To sum up, we have seen above that by the fifteenth century a number of small technical changes had taken place. Before we move on to the study of Renaissance and the Industrial Revolution, let us assess the effect of all these technical advances on the economy and ideas of the late Middle Ages. This is necessary because the feudal system contained the seeds of its own transformation.

6.2.2 The Transformation of Medieval Economy

The new techniques led to greater production in agriculture and, therefore, a surplus from the needs of people. Increased productivity led to greater trade which was aided by better modes of transport. Production of other articles such as cloth, chemicals, wine, and iron for tools and weapons also expanded, leading to a considerable increase and diversification in trade. The more the trade grew, the more money it brought in by way of profit to the merchants, who traded the goods produced by peasants and urban workers. The increased profit led to the manufacture of more goods and production of cash crops from the land. With better techniques, better modes of transport and ample markets, the production of commodities for sale increased considerably. Thus, a trading and urban manufacturing economy grew inside the feudal system. These changes succeeded in breaking down the local self sufficiency of feudal economy at the local village level.

Although, the manufacture of commodities was carried on more often in the countryside as a part-time peasant occupation, the markets were dominated by town merchants. By the mid-thirteenth century, the merchants had become rich and powerful enough to acquire a monopoly position in trade. They had formed guilds and used their position to buy goods cheap, and sell them at huge profits. As the markets expanded, the merchants wanted freedom of movement as well as safety along the trade routes which passed through numerous feudal estates with their own laws and restrictions. A clash of authority between the feudal landowners and the new-rich merchant class was taking place all over. Gradually, the merchants gained the upper hand. By the fifteenth century, they had grown so strong that they were beginning to transform the economy. The feudal economy, characterised by agricultural production based on forced services of the serfs, was transforming into one in which commodity production by craftsmen and hired workers, and money payments became dominant.

These economic, technical and political changes were accompanied by changes in the Church. Till this time the Church was all-powerful. It had a monopoly of learning and even of literacy. The Church had a hold on the state and was deeply involved in the maintenance of feudal order. As the rising merchants and artisans of the towns threatened the feudal order, the might of the Church began to be questioned. The Church tried to suppress all such people by branding them as heretics. However, in the last two centuries of the Middle Ages, the Roman Church was considerably weakened. In some places, kings started asserting themselves against the central authority at Rome. In this they were helped by merchants, though the country nobility was still aligned with the orthodox Church. Thus, the unity of the Church began to be threatened. Between 1378 and 1418, the Christian Church was split between two or three Popes. More authority had to be given to the general councils of the Churches. Substantial movements of reform in the Church were initiated and there was soon to be a struggle for power between the Pope and the Emperors.

It is obvious that the European society, in general, was on the threshold of major changes around the beginning of the fifteenth century. The stage was set for the full flourishing of the Renaissance. In the next section we will describe the changes ushered in by the Renaissance and how they moulded the future development of science.

AQ 2

Ve are listing the factors responsible for the breakdown of feudal economy. Fill up the blanks complete the following statements:

Better techniques led to increased production of .... With better modes of transport and growing markets .... expanded considerably. This destroyed the locally .... character of the feudal economy.

ii) Merchants dominated the markets and huge .... made them very powerful. They came in conflict with the .... and gradually gained the upper hand.

iii) Production of commodities for sale and payment in terms of .... became dominant and replaced agricultural production by .... based on their forced service.

We have seen above, that the technical improvements introduced in the latter half of the Middle Ages led to a greater available surplus in agriculture and other goods. This spurred a rapid expansion of trade which was also increased by improvements in shipping and navigation. The consequent economic changes from a feudal economy to an economy based on commodity production and money payments were accompanied by momentous social changes. In fact, these changes led to a movement for changing the social system from that based on a fixed hereditary status to one based on buying and selling commodities and labour. The Renaissance and the Reformation are two aspects of this movement. We will now describe what this movement was and examine, in brief, its impact on the scientific and technological developments.

6.3 THE RENAISSANCE (1440-1540)

The Renaissance was a revolutionary movement. It marked a definite and deliberate break with the past. It swept away the medieval forms of economy, of building, of art and thought. These were replaced by a new culture, capitalist in its economy, classical in its art and literature, and scientific in its approach to Nature. The feudal system dominated by the lords and the Church had given way to nation-states, where the kings or princes provided patronage to the new scientists. So they didn't have to depend any more on the Church. With the economy picking up again, the despair of the Dark Ages and the resignation of the ages of faith gave way to a period of hope marked by a frank admission of physical enjoyment. In the changing social milieu, money became much more important than it had ever been before. Even the attitude towards making money changed. Any way of making money was good as long as it worked, whether by honest manufacture of trade, by inventing a new device, by opening a mine, by raiding foreigners or by lending money at interest.

Renaissance was the transitional movement in Europe between medieval and modern times. It began in the 14th century in Italy and lasted into the 17th century. It was marked by a humanistic revival of classical influence expressed in a flowering of the arts and literature and by the beginning of modern science.

In these changed social conditions, the technicians and artists were no longer so despised as they had been in classical or medieval times because they were essential to the making as well as spending of money. The practical arts of weaving, pottery, spinning, glass making, mining, metal-working etc. became respectable. Initially, this enhanced the status of craftsmen. But later, by the seventeenth century the merchant and the capitalist manufacturers started controlling the production more and more. As a result, both craftsmen and peasants were reduced to the status of wage labourers.

In its intellectual aspect, the Renaissance was the work of a small and conscious minority of scholars and artists who set themselves in opposition to the whole pattern of medieval life and thought. The Renaissance also re-established the link between the traditions of the craftsmen and those of the scholars. With this coming together of the doers and the thinkers in the changed economic situation, the stage was set for a rapid growth in science. Let us see what changes occurred in science and technology during this period.

6.3.1 Science and Technology during the Renaissance

This phase in the history of science was one of description and criticism. First came the exploration of ancient knowledge, mainly of the Greeks. The scholars encountered the thoughts of Plato and Aristotle in the original, as well as those of Democritus and Archimedes. Then came the challenge to old authority. At the same time the arts and techniques flourished and provided the material means for the growth of science.

Art

The visual arts, such as painting and sculpture, came to occupy an important place in society. These had a profound influence on the development of science. For instance, painters were required to have a thorough knowledge of geometry, so that they could represent three dimensional figures in two dimensions. For this, they also used many mechanical and optical aids. The realistic life-like paintings required the most detailed observations of nature and thus, aid the foundation of geology and natural history. The anatomy of human beings was also studied in much detail.

The professions of artists, architects and engineers were not separated in the Renaissance. Artists were also the civil and military engineers. They could cast a statue, build a cathedral, drain a swamp or even besiege a town. The great Renaissance artist Leonardo da Vinci is well known to all of us for his beautiful painting 'Mona Lisa'. Not many of us may know of his contributions to the study of human anatomy, study of plants and animals as well as of machines and military devices (Fig. 6.4). His drawings indicate that he was also a keen observer of the operations of metal-workers and technicians who constructed buildings and bridges.

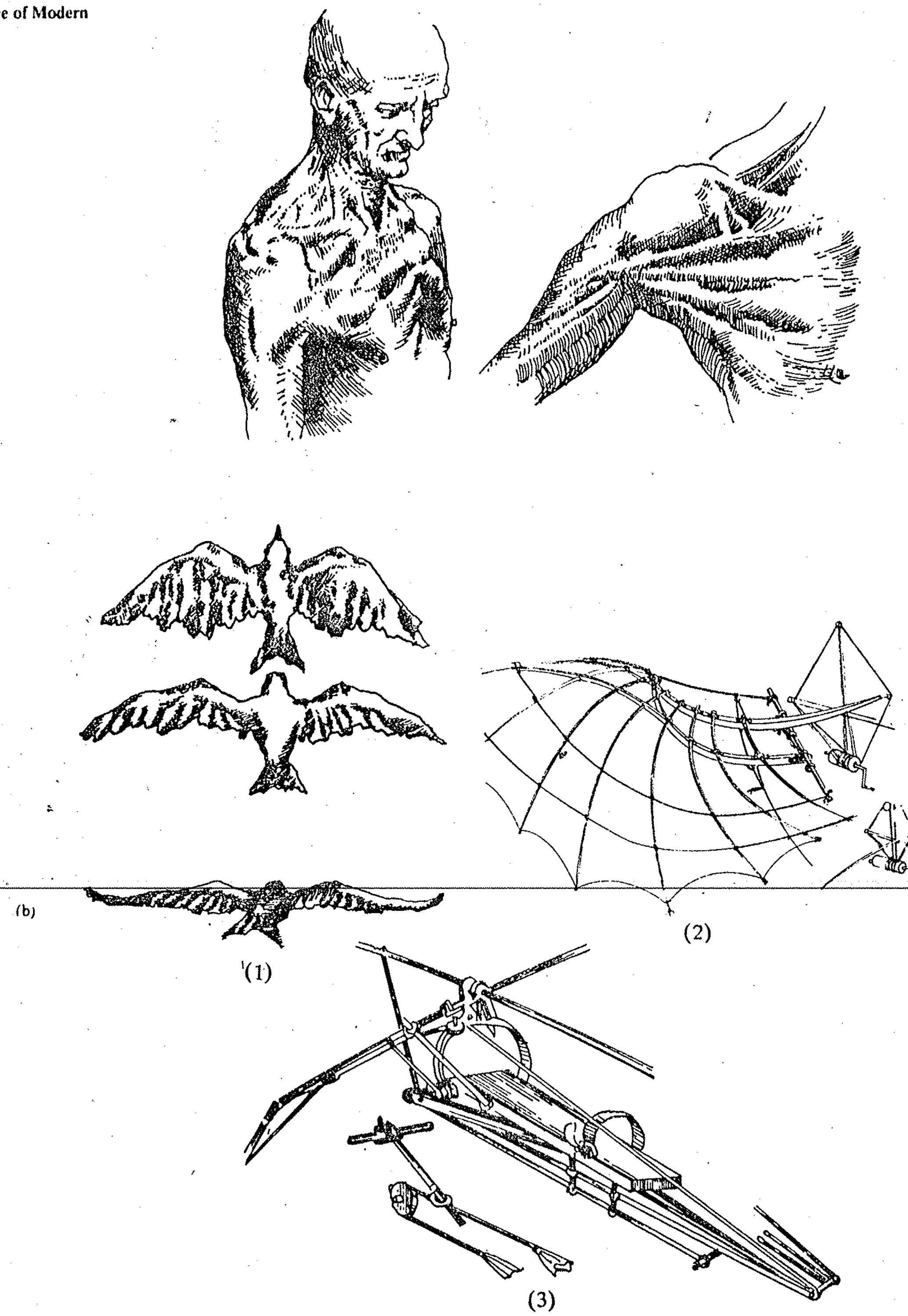

Fig. 6.4: Sketches of Leonardo da Vinci : (a) anatomical studies of muscles; (b) Leonardo designed the first flying machine—he spent years observing birds in flight (1); an early flying machine—a wooden wing hooked up to a hand crank (2); flying machine (3).

Medicine and Technology

The faculties of medicine in the universities, especially in Italy, were the first ones to break out of the general obscurantism. The doctors mingled freely with artists, mathematicians, astronomers and engineers. These associations gave European medicine its characteristic descriptive, anatomical and mechanical bent. The human body was dissected, explored, measured and explained as an enormously complex machine. The new anatomy, physiology and pathology were founded on direct observation and experiment. Thus, the hold of classical ideas of humours and elements, about which you have read in Unit 3 began to be broken.

In technology, the greatest advances of Renaissance were in the fields of mining, metallurgy and chemistry. The need for metals led to the opening up of mines. With growing capitalist production, mining became a large scale operation. As mines grew deeper, pumping and hauling devices became essential. This led to a new interest in mechanical and hydraulic principles.

The smelting of metals like iron, copper, zinc, bismuth, cobalt etc., their handling and separation led to a general theory of chemistry involving oxidation and reduction, distillation and amalgamation. For the first time, metallic compounds were introduced into medicine. Other chemical substances such as alum and clay were studied to improve cloth and leather industries or to make fine pottery. By the end of the Renaissance, the chemical laboratory with its furnaces, retorts, stills and balances had taken a shape that was to remain almost the same till into modern times (Fig. 6.5).

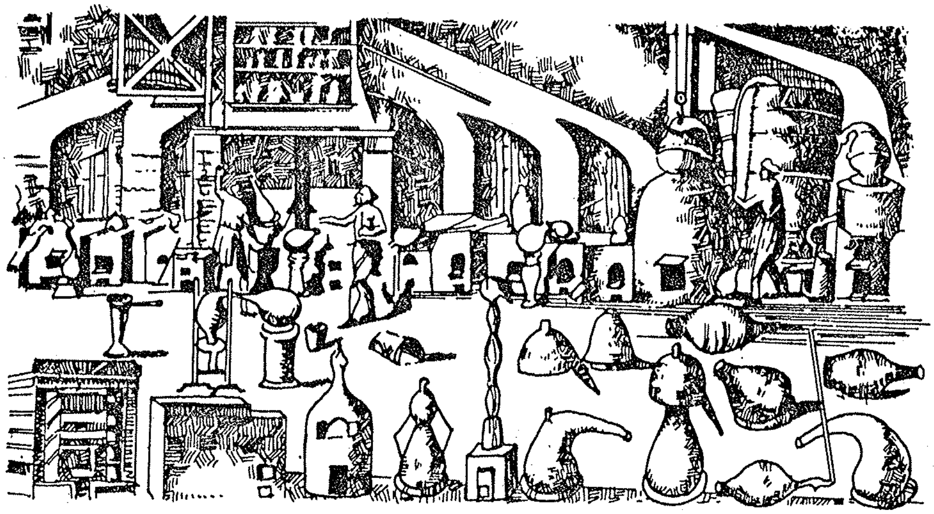

Fig. 6.5: A chemical laboratory of the early eighteenth century.

Navigation and Astronomy

As we have said earlier, by the end of the Middle Ages, trade on land and over the seas was being taken up on a big scale. By the fifteenth century, the Turks had acquired a monopoly of trade routes on land. Therefore, new sea routes for trade were being explored. Great voyages were undertaken. We all know about Vasco da Gama, a Portuguese sailor, who reached India in 1497 via the Cape of Good Hope in Africa. Around the same time, a great and adventurous voyage was undertaken to sail westward on the Atlantic Ocean in the hope of reaching India. Columbus, an inspired adventurer, though a penniless sailor, was able to obtain the assistance of Portuguese, Spanish, English and French courts to undertake this journey. He reached the continent, later named as America, in 1492 thinking that he had reached India. The adventure, the general excitement and ultimately, the great profitability of these voyages created great enthusiasm for building new ships and instruments for navigation. Interest in astronomy was strongly revived.

The Copernican Revolution

It was right in the midst of these developments in the fifteenth century, that there came the first major break from the whole system of ancient thought. This was the work of Copernicus, who gave a clear and detailed explanation for the rotation of earth and other planets on their axis and their motion around a fixed sun which was at the centre. This model simplified astronomical calculations, and also made them more precise. You will read more about the Copernican model in Unit 9. As we have seen in Units 3 and 4, such a model had been proposed by Greek astronomers like Aristarchus many centuries earlier. However, it was not given any importance because it ran counter to the established ideas of those times. This work of Copernicus was published in the very year of his death in 1543. Although his book attracted limited attention and there were objections to his model, his work gave a great boost to further work by Galileo. We will talk about Galileo's work later in Sec. 6.4.

Fig. 6.6: Nicholas Copernicus.

This was the first phase of what we now call the Scientific Revolution. In this phase, the old ways of thought were proving inadequate. By rejecting the old ideas, the men of Renaissance had cleared the grounds for new ideas of the succeeding century. In the use of science for practical purposes too, the Renaissance set the scene for future developments. From now on science had become a necessity for profitable enterprises, trade and war. Later it could extend its service to manufacture, agriculture and even medicine.

SAQ 3

i) List five significant scientific and technical developments during the Renaissance.

ii) What was the Copernican Revolution?

6.4 SCIENCE IN THE POST-RENAISSANCE PERIOD (1540-1760)

We have seen above that improved techniques as well as growing trade had led to great voyages to many lands. These were made in search of spices, silver, fur, sugar plantations, slaves, gold and other commodities. The one to have very far reaching effects was the voyage undertaken by Columbus in 1492, which, eventually, resulted in a lot of Europeans going to America. There they cleared the land, settled down and started plantations of sugar and tobacco exploiting the hard labour of African people. The Africans were forcibly taken on board west-bound ships to be transported to the new country and were sold there as slaves. The stealing, selling and exploitation of people as slaves caused terrible suffering. Yet, it was done unashamedly because there was great profit to be made from the new colonies. Money was being piled up for investment in shipbuilding, mining and manufacturing other articles in Europe.

These developments greatly strengthened the merchant class and over the next two or three centuries they were able to replace the feudal lords and landowners in authority over their regions. Society tensions, peasant revolts, religious wars and the race to acquire colonies were all playing a role in changing the feudal society of the Middle Ages into a capitalist society of the eighteenth century in some areas of Europe. The development of capitalism as a leading method of production was accompanied by the birth of a new method of natural science, that of experiment and observation.

In science, this period from the mid-sixteenth century to the mid-eighteenth century includes the first great triumphs of the new observational, experimental approach. This new approach together with the development in science and technology during the Renaissance, amounted to a "Scientific Revolution". Technically, this period was of steady advance without any revolutionary inventions. The increasing demand for iron led to development of new blast furnaces. The shortage of wood for iron-smelting led to widespread use of coal. From then on, the centre of industry was to move towards the coal fields. With time, the demand for limited resources increased, forcing the search for new resources and techniques. This also altered the attitudes towards change and novelty, which could not be shunned anymore. You may recall that in the regimented feudal society, new ideas and change were resisted.

It was in this atmosphere that European science grew to maturity. The first institute for teaching science, the Gresham College, was opened in England in 1579. As we have already seen, the revolutionary Copernican model of the solar system helped in improving astronomical tables. What the theory lacked was an accurate description of the orbits of the planets. This was done by two remarkable men, Tycho Brahe (1546-1601) and Johannes Kepler (1571-1630). Brahe, collected a series of exact observations on the positions of stars and planets with specially made apparatus. His results were theoretically worked over by Kepler. Kepler found that the observations could be explained only if the orbits were taken as ellipses. Thus, he broke away from the idea of circular orbits. Kepler's laws of planetary motion struck a mortal blow to the old Greek thought of perfect circular motion. You 'll find more details of their work in Unit 9.

The telescope, invented around this time, proved to be the greatest scientific instrument of this period. In the hands of Galileo Galilei (1564-1642), a professor of physics and military engineering at Padua, it became a means of revolution in science. Galileo was able to see that the moon was not a perfect round and smooth body but it had ridges and valleys. He also observed that three moons circled around the planet Jupiter, more or less like the system Copernicus had proposed for the earth going round the sun. Within a month, in 1610, he published his observations in his book *Siderius Nuntius*, (Messenger from the Stars). It created a great sensation because the 2000 year old model of heavenly bodies going round the earth was threatened. It challenged the accepted world view that man, specially created by God, lived on earth, hence, it was natural to believe that the whole universe revolved around the earth.

Fig. 6.7: Galileo Galilei.

Galileo's more detailed work, entitled *Dialogue concerning the Two Chief Systems of the World, the Ptolemaic and the Copernican* was published in 1632 and was, indeed, dedicated to the Pope. In this he criticised and ridiculed the ancient Ptolemaic cosmology. The challenge put down by Galileo could not be ignored. Far more was seen to be at stake than a mere academic point about the motion of the earth and planets. If the challenge in one respect was ignored, more such challenges would arise. The new knowledge threatened the stability of the Church and the social order itself. It immediately led to conflict with the Church which resulted in Galileo's trial. He was condemned and forced to go back on his words.

The trial of Galileo dramatised the conflict between religious dogma and carefully observed and analysed scientific data and theory. It is a sheer chance that the year Galileo died, Newton was born. As we shall see later, Newton was to continue Galileo's scientific tradition. He provided a complete scientific theory of motion of all objects, whether planets in the heavens or bodies on earth. This shows that given the socio-economic conditions of those times, it was not easy any more for the Church to suppress the scientific tradition. Whereas earlier Giordano Bruno (1548-1600) was burnt to death and Campanella (1568-1639) was imprisoned for years for opposing the Aristotelian world view and supporting the Copernican theory, Galileo suffered a nominal imprisonment in the palace of one of his friends. By Newton's time, interference from the Church in science had more or less stopped.

Galileo did not stop even after being tried and condemned by the Church. He tried to explain how the Copernican system existed. For this, it was necessary to explain how the earth's rotation did not produce a mighty wind blowing in the opposite direction and how bodies thrown in the air were not left behind. This led to a serious study of bodies in motion. On the basis of carefully conducted experiments, Galileo succeeded in formulating a mathematical description of the motion of bodies. This was the major work of his life expressed in his *Dialogue on Two New Sciences.* Galileo questioned all accepted views. This he did by the new method, the method of experiment. When Galileo's experiments gave him results he did not expect, he did not reject them. Rather, he turned back to question his own arguments. This was the hallmark of experimental science.

Galileo and Kepler could formulate mathematical descriptions of the motion of bodies because they were masters of the new mathematics that had grown during the Renaissance. Algebra, geometry and the decimal system, taken from the ancients and the Arabs, as well as the introduction of logarithm by Napier (1550-1617), greatly simplified astronomical calculations. Forty years later, the observational laws of Kepler were combined with the explanations of Galileo in Newton's theory of universal gravitation. We will talk about it shortly.

There were other important developments in science in this period. Magnetism was experimentally studied for the first time. Another important development was William Harvey's (1578-1657) discovery of the circulation of blood in the human body. Once again, it led to a complete break from Galen's ideas which we have described in Unit 3. A totally new approach was formulated and the human body was analysed on the principle of pumps and valves like the ones seen in machinery. As a result, a new kind of experimental anatomy and physiology emerged.

The developments in the latter half of the seventeenth century paved the way for an outburst of activity which created modern science in most of its fields in the next fifty years. These were helped by the emergence of stable governments in France and England, the two principal centres for scientific activity in those times. The merchants in Britain had arranged a compromise with landlords, in which the king became the constitutional monarch. The economy was dominated by the merchants. But, more importantly, a new class of manufacturers was emerging from among the skilled craftsmen. The courtiers and the learned men of the universities, dependent on the favour of the princes of yesteryears, were being replaced by men of independent means. These were mostly merchants, landowners, doctors, lawyers and quite a few parsons. They financed science out of their pockets. As they grew in number, they tended to come together for discussion and exchange of ideas.

Thus were formed the first well-established scientific societies, the Royal Society of London (1662) and the French Royal Academy (1666). These societies set themselves the task of concentrating on the pressing technical problems of those times, those of pumping and hydraulics, of gunnery and of navigation. In science, it appeared at first that anything and everything could be improved by enquiry. However, certain fields of interest drew special attention. Those were the ones directly related to the needs of expanding trade and manufacture. Foremost among these was astronomy which was an essential need of ocean navigation. The developments in astronomy led to the new mathematical explanation of the universe, finally arrived at by Newton. This was a major triumph of science.

Fig. 6.8: Isaac Newton.

The greatest triumph of the seventeenth century was the completion of a general system of mechanics. This system could explain the motion of heavenly bodies as well as the motion of matter on the earth in terms of universal laws and theories. Many mathematicians and astronomers including almost all great names of science of that period—Galileo, Kepler, Descartes, Hooke, Huygens, Halley and Wren, had worked to find this complete form of mechanics. Standing on the shoulders of these giants, it was ultimately Newton who worked out and proved his theory of universal gravitation and set it down in his *'De Philosophiae Naturalis Principia Mathematica'*.

Newton's theory of universal gravitation applied to all particles or bodies possessing mass, whether on the earth, on the sun, or anywhere else in the universe. Newtonian mechanics, as it is known to us now, provided a coherent explanation for the motion of all bodies in this universe, i.e. how bodies moved as they did. By the use of Newtonian mechanics it was possible to determine the path of any body in motion, if all the forces acting on it were known. Newton's laws of motion are now taught in all the science courses all over the world. The immediate practical consequence of Newton's work was that the position of the moon and the planets could be determined far more accurately with a minimum of observations. It also became the basis for the design of a great diversity of machines and structures which are used today and will be used for centuries to come.

Newton's theory of gravitation and his contribution to astronomy mark the final stage of the transformation of the Aristotelian world-picture begun by Copernicus. Newton established a dynamic view of the universe in which things were changing with time. Yet, he stopped short of questioning the existence of a divine plan. His world moved according to a simple law, but it still needed divine intervention to create it and set it in motion. His theory gave no reasons why the planets went round the same way. He postulated that this was the will of God at the beginning of creation. Newton felt he had revealed the divine plan and wished to ask no further question. By Newton's time, the phase of criticism in the Renaissance was over. A new compromise between religion and science was being sought. Newton's work provided this basis for a compromise between science and religion which was to last until Darwin upset it in the nineteenth century.

There were other developments too, such as in optics and the theory of light, closely linked to astronomy by the telescope and to biology by the microscope. Seventeenth century optics grew largely from the attempts to understand refraction. At the same time, theories about the nature of light were also given. Another development was pneumatics, the science of mechanical properties of gases. The question of vacuum was also important. The actual production of vacuum and the use of air pump for this led Robert Boyle to study the behaviour of air. Thus, it led to his epoch-making work on the gas laws. Robert Hooke, an assistant of Boyle, was the greatest experimental physicist of those times. His interests ranged over the whole of mechanics, physics, chemistry and biology, though he is best known for his study of elasticity.

The world of biology saw great advances with the coming of the microscope. Small creatures were observed and the anatomy of larger ones was refined. In chemistry, new substances such as phosphorus were accidentally produced and new metals such as bismuth and platinum were discovered. The demand for new chemicals led to a growth in the chemical industry.

SAQ 4

In the table given below, match the names of the scientists of the post-Renaissance period listed in column 1 with their works listed in column 2.

1	2
a) Tycho Brahe	i) Developed the table of logarithms.
b) Johannes Kepler	ii) Made observations on planetary motion.
c) Galileo Galilei	iii) Discovered laws of planetary motion.
d) John Napier	iv) Formulated gas laws.
e) William Harvey	v) Established sun-centred model of the solar system; gave mathematical description of motion of bodies.
f) Isaac Newton	vi) Discovered the law of elastic properties of matter.
g) Robert Boyle	vii) Discovered blood circulation.
h) Robert Hooke	viii) Gave the theory of universal gravitation.

Thus, we find that in this period of the Scientific Revolution, the new approach to science, based on observation and experiment, led to pathbreaking advances in many areas like mechanics, astronomy and biology. They also set the stage for further activity which created modern science in many other fields. The prevailing social conditions in Europe were also very conducive to the growth of science. We will now discuss some of the features of European society that helped the rapid development of science there.

6.4.1 Why Science Grew in Europe

Looking back over the development of the new science in the fifteenth to the seventeenth centuries, we can understand why the birth of science occurred when and where it did. We have seen that it closely followed the revival of trade and industry. The profit from expanding trade and successful voyages was being invested in new activities giving rise to a climate of intellectual enterprise. The birth of modern science follows closely after that of capitalism. The merchants and gentlemen of the seventeenth century had cleared the ground for the flourishing of a humbler set of manufacturers. These were the ones who made use of and developed the traditional techniques beyond all recognition in the next century. In science, as in politics, a break with tradition also meant venturing into hitherto unknown areas. No part of the universe was too distant, no trade too humble, for the interest of the new scientists. The fact that these scientists often interacted with each other, established societies and published journals also helped the advance of science.

Science was also able to flourish as it did because of the Church's internal feuds, its friction with the emerging merchant class and a general erosion of its authority. The resistance of the Church to scientific ideas seemed to be quite strong in the beginning. This was evidenced by the trial of Galileo and by the execution of Bruno who uttered the heresy that just like our own world, there may be other worlds in the heavens. But later on the success of the new scientific thinking based on observations was unstoppable.

As we have said earlier, a compromise was being sought between science and religion. Hence, ways and means were explored to find a way of coexistence between science and religion. This was to be on the basis that science should deal with the phenomena which affect the senses, but it should leave aside other matters which are spiritual or aesthetic in nature. An artificial divide which we see even today was, thus, created between science, social science, arts and humanities. On the other hand, from the time of Newton onwards, scientists were able to work with greater freedom, and with practically no interference from religion. As we have seen, scientific societies were established to see that the advancement of science was linked to practical benefits, to business or to society at large.

The success of science in this period was also due to the working together of the people who produced or manufactured different articles, and the scientists who tried to understand the properties of materials that were being handled. This was because manual work was given greater social prestige as it was a source of great profit. The economic and social world had changed from one with the fixed hierarchical order of the classical and feudal period where each human being knew his or her place. Now, it was a world of individual enterprise where each human being paved his own way.

These exciting developments in Europe had two facets. Expanding production and trade and the resulting search for markets led to European entry into many countries of Asia, Africa and North and South America. Colonies came into existence and their wealth began to flow into the European countries, which improved the lot of even the common man in these countries. On the other side, it was a misfortune for the colonial people whose crafts and industry were ruined and whose natural resources were harnessed for export to the ruling countries. The role of the East India Company in bringing India into the colonial system is well known. Extreme poverty and deprivation in India has its origin in the colonial exploitation of our land and our people. We shall talk more about it in Unit 7.

We will now tell you about a major event towards the second half of the eighteenth century, viz. the **"Industrial Revolution"** in Europe, particularly in Great Britain. This arose from the ability to use steam powered machines on a large scale, resulting in a radical change in the means and the mode of production. It also resulted in bringing about deep-seated changes in the structure of the society.

6.5 THE INDUSTRIAL REVOLUTION (1760-1830) AND AFTER

We will first give a brief description of the social and economic changes of this period so that developments in science can be seen in the proper perspective. Already, by the end of the seventeenth century, the stage was set for the further advance of the capitalist mode of production. The feudal and even royal restrictions on manufacture, trade and business had been swept away. The triumph of the bourgeoisie, and of the capitalist system of economy which they had evolved, had taken place only after the most severe political, religious and intellectual struggles.

In Britain, the urban middle class had broken away completely from feudal limitations by the eighteenth century. With an ever increasing market for their products all over the world, they could finance production for profit. With an expansion of markets, growing freedom from manufacturing restrictions and increasing opportunities for investment in profitable enterprises the time was ripe for great technical innovations.

Thus, we find that by the middle of the eighteenth century, the slow and gradual changes in the production of goods gave way to a rapid change. The new methods of experimental science that emerged from the Scientific Revolution of the sixteenth and the seventeenth century were now extended over the whole range of human experience. Their applications in creating new techniques brought about the great transformation of the means of production which we call the Industrial Revolution. The architects of the Industrial Revolution were artisan inventors. Workmen with their small accumulated or borrowed capital were, for the first time, establishing their claim to change and to direct the production processes. The domination of merchants over the production of small artisans was also being broken.

The Industrial Revolution came mainly from developments in industry, that too within the major industry of those times: the textile industry. As the demand for cloth increased, the old industry could not expand rapidly to meet it. Also, by 1750, the industry came to deal with a new fibre, cotton. Earlier, cotton cloth had been imported from India. With the import of cotton textile from India into Britain being prohibited, there was a great impetus to increase production of cotton textiles. The use of cotton called for new techniques. Here, at last, in the cotton industry there was unlimited scope to substitute machinery for manual work. Thus, from the technical changes which had been taking place for many decades, came the idea of introducing several mechanical gadgets for spinning and weaving. Manual work was greatly reduced as machines replaced the operations that were done by hand (Fig. 6.9).

The textile industry led the way to developments in other areas as well. The market for textile machinery and textile processing stimulated the iron and chemical industries. All these industries called for an ever increasing supply of coal, which required new developments in

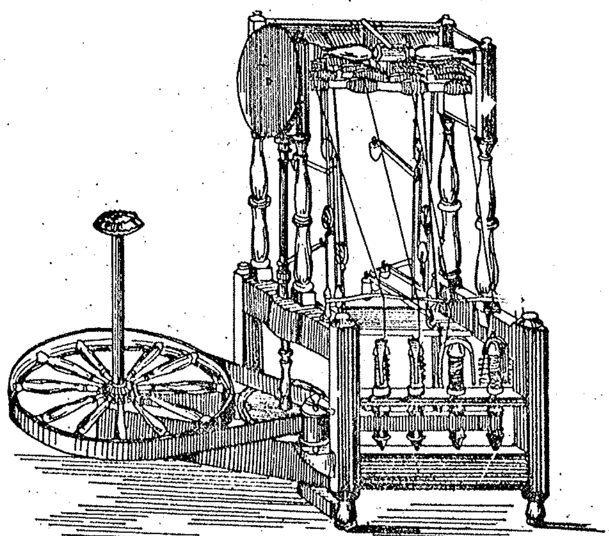

Fig. 6.9: A spinning machine which could spin much faster and produce much stronger thread than the old spinning wheel. It made possible a cloth woven of cotton alone, rather than cotton mixed with flax as in the past.

mining and transport. The new mechanical industry developed around coal fields. However, it was the use of the steam engine for power in the textile industry that really created the industrial complex of the modern world. It revolutionised textile production, so much so, that production of goods increased almost five fold within 20 years.

The idea of mechanisation rapidly spread to other areas such as mining, metallurgy and even agriculture. Very soon the attention of the entire society was drawn to its explosive potential. With soaring profits, the search for markets became more acute. It became necessary to have radically new means of transport and communication to carry on this trade. The steam engine, as a stationary device, had long been used in mines and then in "factories" which had come into existence. Now it was put on rails to draw heavy loads over long distances. Thus, the railways linked the centres of industry; and the steamships collected its raw materials and distributed its finished products far and wide.

While the eighteenth century had found the key to production, the nineteenth century was to find that to communication. Electricity had been used as long ago as 1737 to transmit messages for distances of a few kilometres. But now it was absolutely necessary to transact business over long distances. This was ensured by the successful invention of the telegraph in 1837. Soon, wires were laid for speedier communication between towns, from one country to another. By 1866, across the Atlantic Ocean, on its bed in the form of cables, wires were laid to form a telegraphic link between Britain and America. Within a hundred years from the beginning of the Industrial Revolution, factory towns had sprung up and the appearance of even the countryside had changed. A complete transformation had taken place in the lives of millions of people living in the newly industrialised countries like Great Britain, France, Germany, Holland, USA etc.

Introduction of machines in production centres which moved from homes to specially constructed premises called factories, led to reorganisation of work, and, in particular, to "division of labour". This meant that complex operations were broken down into simpler ones, and one man at his workplace performed only one or two very simple operations. Thus, the production per person was greatly enhanced. However, at the same time, this increased human drudgery, reduced requirement of mental involvement, and, in fact, made human beings work like machines (Fig. 6.10).

It is known these days that, in general, "industrialisation" makes one person produce many times more surplus than agriculture. More surplus yields more profits. Therefore, capital gets multiplied much more rapidly, and it can be used to put up more machines for more production. Hence, the tendency is to multiply production as a whole. What is produced must be sold, and hence the market must also expand all the time. However, in the home market, buyers must also have the cash to buy the product. This creates a dilemma—profits have to be maximised, but what if the workers cannot buy the product? There is no safe formula to determine the worker's share in the profit and hence such a system is prone to social and economic problems.

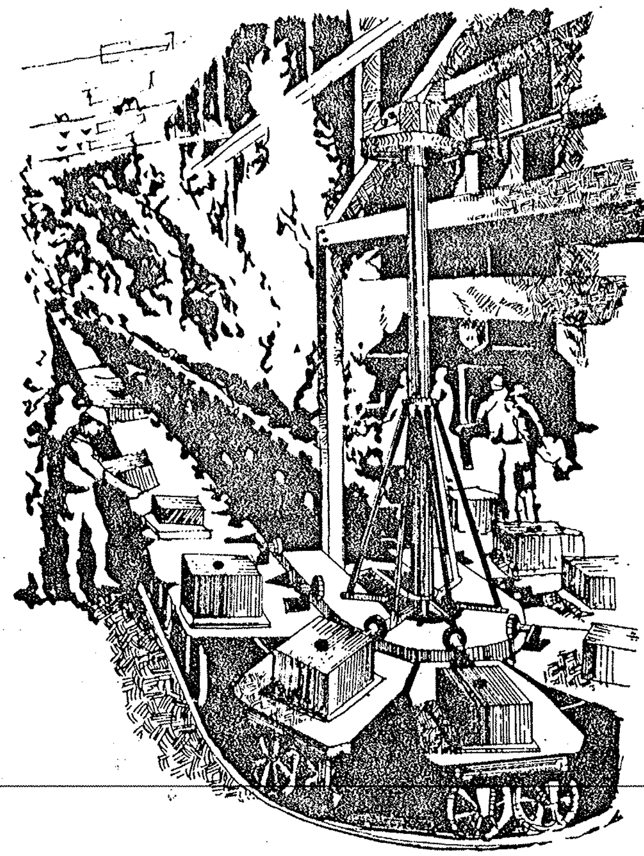

Fig. 6.10: Industrial production in which a worker carried out the same simple task repeatedly. In this sketch, a worker is placing blocks on a series of tables which, put on wheels, move on a track through the casting, moulding and other rooms of a factory.

The history of early industrialisation in all countries shows how workers were exploited, how every ounce of the workers' energy was extracted so that the machines could churn out huge profits; and how miserable were the conditions in which the workers had to live. This gave rise to the new phenomena of trade unions and workmen's struggle to improve their lot.

There was another aspect of this industrialisation. With increase in production, the cost of production came down. Since goods were produced on a large scale, the overhead costs did not increase proportionately. Thus, industrially produced goods turned out to be cheap. This led to goods from industrialised countries swamping markets in the colonies and ruining local industry. Where the industrial goods were not competing well, the colonial governments went out of their way to use their authority to ensure the sale of imported products.

SAQ 5

a) Which three among the following technical innovations led to the Industrial Revolution? Tick the correct answers.

   i) Mechanical clocks.

   ii) Mechanical gadgets for spinning and weaving.

   iii) Use of steam-powered engine.

   iv) Telegraph.

   v) Mechanical devices for use in mining, metallurgy and agriculture.

b) State, in the boxes provided, whether the following statements about the consequences of Industrial Revolution are true or false. In the case of a false answer, write the correct answer also in the given space.

i) Factory towns had come up changing the entire countryside. ☐

ii) The division of labour led to better working conditions for the workers. ☐

iii) Colonisation of countries meant that industrial goods were made in colonised countries and sold in industrialised countries. ☐

iv) Industrialisation also led to increased exploitation of workers. ☐

v) The telegraph was invented to facilitate long distance communication for business purposes. ☐

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It may be said that science did not play a direct role in the Industrial Revolution—but, of course, technology did. On the other hand, technological understanding and design of machines depended on science—particularly Newton's ideas on motion, force, power and energy etc. The steam engine, the centre-piece of the Industrial Revolution which was used in factories, railways and steam ships, owes a great deal to a correct understanding of the nature of heat and the behaviour of gases with change of pressure. Purification of ores, casting of machine parts from iron, and printing of cloth gave further impetus to developments in chemistry. Oxygen was discovered by Joseph Priestley (1733-1804) at around the time of the Industrial Revolution. Based on his experiments on combustion, Antoine Leurent Lavoisier (1743-1794), a French scientist formulated a theoretical framework for a rational and quantitative study of chemistry. John Dalton (1766-1844) proposed the atomic theory a few decades later.

Fig. 6.11: Louis Pasteur.

Other sciences soon gathered momentum and the list of inventions or new laws discovered in the decades following the Industrial Revolution is most impressive. The list ranges from the discovery of Coulomb's law in 1770, about the force of attraction or repulsion between two electric charges, to the invention of electric light and the discovery of radio waves towards the end of the eighteenth century. In the mid-nineteenth century, Louis Pasteur's discovery of bacteria and his theory that diseases were caused by germs, provided a great impetus to medicine. It led to the development of immunisation against diseases like anthrax in cattle and rabies in human beings. Pasteur also demonstrated that many of these microbes bring about chemical changes in foodstuffs and that it is possible to select specific microbes to produce products like wines and vinegar. This discovery forms the basis of industrial microbiology which has enabled us to get many precious drugs, like the antibiotics cheaply today. It has also made it possible to explore alternative sources of fuel like biogas, power-alcohol etc. But, perhaps, the most significant contribution of Pasteur was that through carefully designed experiments, he gave a convincing proof against the idea of spontaneous generation of life. He postulated that living beings can arise only from the living and not from non-living matter. Can you believe that almost till the nineteenth century it was widely held, even by some scientists, that life could arise spontaneously from non-living matter?

Around the same time, a major contribution came from Charles Darwin (1809-82) in his revolutionary ideas about biological evolution. Until this time, it was believed that each form of life was specially and separately created and, thus, had a specific place and function in the hierarchy of creation. Through careful observations and painstaking research, Darwin built up a theory about the evolution of different forms of life from some simpler ones. You will read more about Darwin's work in Block 3. Darwin's work destroyed the last justification for Aristotle's philosophy. And its conflict with the Church continues to this day.

Fig. 6.12: Charles Darwin.

To sum up, we have outlined some of the major developments in science and technology in the eighteenth and nineteenth centuries. In this period, capitalism came fully into its own and with it science came of age. It completely shed the ancient and medieval myths, and replaced them by a rational analysis of observed or experimented phenomena. In this manner, it helped to carry the Industrial Revolution to great heights and to spread it to several European countries. Science and technology are now recognised to be essential ingredients of industrialisation. This has yet to take place in most countries which were under colonial domination till recently.

Science education was introduced as a subject in some universities in Europe even during the eighteenth century. However, it spread widely during the nineteenth century when scientific academies were founded in many countries and scientific research took root in many European centres. The Industrial Revolution and science grew hand in hand, and if the Industrial Revolution bears certain characteristics of science, science too carries several features of that revolution, as we will soon examine.

Unfortunately, these developments in industrialised countries further strengthened or expanded their colonial hold. India came under colonial influence almost at the same time as the Industrial Revolution and we suffered all the negative effects. Our industry was undermined, our natural resources were packed off, as much as possible, to England which would manufacture articles and force them on our market. Disruption of social life and extreme poverty began at the same time. Although science was irresistibly growing in the West, our education and research were completely neglected. Thus, India fell back in the race of economic development by at least a hundred years. Since the international rate of scientific progress is very high, this tragedy nearly means that scientifically we are likely to be dependent on the West, perhaps, forever, unless we take extraordinary measures to pull ourselves up. We will take up this discussion in detail in the next unit.

It would be interesting for you if we went on to explore the relation between science, technology and society in the present-day world. But we would not be able to do justice to such an exploration without discussing the various branches of science and technology and their special role. In this course, through the units that will follow, you will begin to appreciate the present situation by studying problems of health, food, agriculture and industry, which will be presented in our social context.

6.6 SUMMARY

In this unit, we have covered a long period from the fifth century A.D. to the nineteenth century A.D. This was a period of momentous changes which led to the emergence of modern science in Europe. Let us summarise what we have read in this unit.

- The regimented thinking in the stagnant feudal society did not allow significant growth of science in Europe in the Middle Ages. However, there were many technical developments necessitated by the expansion of agricultural land and the need for its better use at the time when there was a shortage of labour.
- Surplus produce led to trade which encouraged further production. Slowly, the hierarchical feudal order based on the forced service of serfs gave way to a trading society in which commodity production and money payments became dominant.
- The hallmark of the Renaissance were criticism and rejection of medieval thought. The Copernican Revolution was an important scientific development of this period.
- The post-Renaissance period saw the emergence of a new method of science—that of observation and experiment. There were a series of path-breaking advances in science in this period, foremost among them being the works of Galileo, Harvey and Newton. It also set the stage for the birth of modern science in many other areas.
- The Industrial Revolution in Great Britain radically altered the means of production. With this, the transition from a feudal economy to capitalist economy was complete in that country. The social structure also changed accordingly. The feudal hierarchical order with a fixed hereditary status gave way to the enterprise and monetary status of an individual. Modern science and technology came of age in this period, and from then onwards, there was no looking back.

6.7 TERMINAL QUESTIONS

1) Against the technical innovations listed below, describe in one or two lines, the social, economic, political or scientific consequences of each of these, which helped the transformation of medieval economy.

   i) The horse collar ....

   ....

   ii) Wind-mills and water-mills ....

   ....

   iii) Compass and sternpost rudder ....

   ....

   iv) Gunpowder ....

   ....

   v) Paper and printing ....

   ....

2) State at least three developments that helped the advance of science and technology during Renaissance.

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3) In the following table we have compared the features of European and Indian societies from the sixteenth to the eighteenth century, that helped or impeded the growth of science in Europe and in India, respectively. Describe the corresponding features of both the societies in the blank spaces left below. You may have to look up Sec. 5.4 once again.

	European society	Indian society
i)	After severe conflict, the hierarchical feudal order had given way to a climate of individual enterprise and one in which monetary status mattered. This paved the way for greater freedom of thought and action.	....
ii)	....	The hold of orthodox religious priests had stifled creative and innovative thinking in society.
iii)	Manual work had acquired greater social prestige. Artisans and craftsmen who produced goods mixed on equal terms with the scientists and thinkers.	....

iv) .... Knowledge was limited to only a few.

4) What was the difference between the science of classical and feudal times on the one hand and science of the time after the Renaissance on the other?

....

....

6.8 ANSWERS

Self Assessment Questions

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

2) i) commodities, trade, self-sufficient

   ii) profits, feudal lords

   iii) money, serfs

3) i) Study of human anatomy; representing three-dimensional figures in two-dimensions; detailed observations of nature; pumping and hydraulic devices in mining; building new ships and instruments of navigation; Copernican Revolution.

   ii) Copernicus proposed a model of the solar system in which the sun was at the centre and all planets including the earth rotated around it. It was revolutionary as it completely rejected the ancient geocentric model.

4) a) ii), b) iii), c) v), d) i), e) vii), f) viii), g) iv), h) vi)

5) a) i) × ii) ✓ iii) ✓ iv) × v) ✓

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

   ii) Instead, it increased the workers' drudgery and reduced their mental involvement, turning them into virtual machines.

   iii) Colonised countries supplied the raw materials and served as markets for finished goods of the industrialised countries.

Terminal Questions

1) i) More acres of land could be cultivated leading to surplus agricultural produce for trade.

   ii) Helped in agriculture, forging iron or sawing wood and in overcoming the labour shortage.

   iii) Opened the oceans for voyage leading to increased trade with far off lands which led to developments in astronomy, geography and the industry of making navigational instruments.

   iv) Led to studies in chemistry, mechanics and breathing.

   v) Aided the spread of literacy and increased people's access to education.

2) i) The status of technicians, craftsmen and artists was enhanced as the practical arts flourished.

   ii) Scholars questioned and challenged the medieval thought.

   iii) Links between craftsmen and scholars were re-established.

   iv) The method of observation, experiment and calculation became the new method of science.

3) i) The social order was stable. There was general satisfaction among the population with no clamour to bring about change.

   ii) In the changing social conditions, a compromise was worked out between science and religion. From the seventeenth century onwards there was no religious interference in science.

   iii) The learned people in the society did not interact with the manual workers who were not considered respectable.

   iv) Printing made education and information about science and technology available to people at large.

4) Earlier works in science were mostly based on speculation about the world around. After the Renaissance, observation, experimentation and calculation, accompanied by a will to question and revise one's assumptions, became the new methods of science.

UNIT 7 SCIENCE IN COLONIAL AND MODERN INDIA

Structure

7.1 INTRODUCTION

We have seen in Unit 6 that the Industrial Revolution had led to an ever increasing demand for raw materials as well as markets for finished products. The newly industrialised countries took care of their growing demands by colonising many Asian and African countries. By the mid-nineteenth century, the British had established their colonial rule in India. The fairly long Indian tradition of science and technology and a rich cultural heritage, about which you have read in Units 2 to 5, got destroyed due to the merciless exploitation perpetrated by the colonisers. Only after Independence did we become the masters of our destiny and chose to consciously use science for the benefit of our people.

In this unit, we will outline the development of science and technology in India during the colonial and the post-Independence period. We will also try to analyse some pertinent issues relating to science and our society in the light of what we have learnt in the previous units.

Objectives

After studying this unit you should be able to :

- outline the few scientific developments in colonial India and analyse why these were so meagre,
- describe the impact of the freedom movement on the developments in science in pre-Independence India,
- describe the problems before our country after Independence and our response to solving them,
- discuss various issues related to the use of science and technology in our social context.

7.2 SCIENCE IN COLONIAL INDIA

We have seen in Units 5 and 6 that from the sixteenth century onwards, Europe began to outdistance India in scientific and material advancement. The rise of modern science in Europe strengthened European economic domination over the colonies where education, science and research were kept backward.

The advancing European trading companies of Holland, Portugal, France and Great Britain became deeply involved in political and military rivalries in India. The British East India Company emerged as the dominant trading company. This culminated in the establishment of the British supremacy over the Indian sub-continent. This was a very exciting time for the British rulers; a new empire was in the making and in the process of consolidation. The colonisers were out to collect the maximum possible information about India, its people and resources. They faithfully reported what was best in India's technological traditions, what was best in India's natural resources, and what could be the most advantageous for their employers. The rulers were also quick to realise that a thorough knowledge of the geography, geology and botany of the areas being conquered was essential. They fully recognised the role and importance of science in empire-building. Let us now see what the few scientific developments

To the colonial times in India were. We will also try to analyse why there were so few developments.

An interesting feature in the early phase of this period was that colonial scientists would try their hand at several fields simultaneously and each scientist was, in fact, a botanist, geologist, geographer and educator—all rolled into one. As data-gatherers, the individual scientists were efficient. However, for analysis and drawing conclusions, they had to depend upon the scientific institutions in Britain, which received such data from many colonies. The British made investment in botanical, geological and geographical surveys from which they hoped to get direct and substantial economic and military advantages. Medical and zoological sciences did not hold such promise and, thus, they were neglected. Research in physics or chemistry was simply out of question because these subjects were related to industrial development which the British did not want to encourage. India was considered to be only a source of raw materials and a wonderful market for all sorts of articles manufactured in Britain, from needles, nibs and pencils to shoes, textiles and medicines.

However, the setting up of some scientific bodies and museums was a positive step. Pre-British India had a weak scientific base and, therefore, neither scientific institutions existed nor were there any journals to spread scientific information. William Jones, a judge of the Supreme Court of Calcutta and some other European intellectuals in the city realised this and founded the Asiatic Society in Calcutta in 1784. This society soon became the focal point of all scientific activity in India. It was followed by Agricultural-Horticultural Society of India (1817), Calcutta Medical & Physical Society (1823), Madras Literary and Scientific Society (1818), and the Bombay Branch of the Asiatic Society (1829). These societies rendered invaluable service, particularly through their journals which compared very favourably with the European ones.

When the Crown formally took over the Indian administration in 1858, activities for exploring the natural resources in the country had already passed their formative stage. The problem was more of consolidating the gains which individual efforts had made possible. For this, many institutions were set up and the government expanded the survey organisations. In 1878, the three survey branches—the trigonometrical, topographical and the revenue which had upto that time been separate departments, were amalgamated. Naturally, Revenue Survey got the upper hand. Similarly, geological explorations were patronised because of their direct economic benefit. The Geological Survey of India was created in 1851. Unlike the Geological Survey or Survey of India, an organisation for carrying out botanical explorations did not come up.

The establishment and development of various scientific departments and institutions called for a different cadre. The biggest and the oldest was the Indian Medical Service which was raised and maintained basically to serve the army. The most disorganised sector was that of agriculture. Though the maximum revenue came from agriculture, the problems of its improvement were too complex and the government left it in the hands of private agricultural societies. Much later, in 1906, an Indian Agricultural Service was organised. However, it did not grow into a well-knit and integrated scientific department because of financial and administrative constraints. A few branches which were of military or instant economic significance could manage to develop. But, on the whole, the efforts remained adhoc, sporadic and local in nature. The government wanted practical results rather than research papers. An excessive administrative control, exercised at different levels, ensured that the colonial scientists would always dance to the official tune.

In the educational scheme, science was never given a high priority. The charter of 1813 called for 'the introduction and promotion of knowledge of science among the inhabitants of British India'. But it remained a pious wish, at least partly because the indigenous educational system was also not sympathetic to the idea. In 1835, Macaulay succeeded in making a foreign language English the medium of instruction. Also, his personal distaste for science led to a curriculum which was purely literary. The entry of science in schools was, thus, delayed. A few medical and engineering institutions were opened but they were meant largely to supply assistants to British trained doctors and engineers. Ancient universities in India were leading centres of learning in their time and attracted scholars from other countries. So were the famous centres of Islamic learning in the medieval period in India. But these traditions did not survive. It was in 1857 that the Universities of Calcutta, Bombay and Madras were set up more or less on the pattern of London University.

However, it was only in 1870 that the Indian universities began to show some interest in science education. In 1875, Madras University decided to examine its matriculation candidates in geography and elementary physics in place of British history. Bombay was the first to grant degrees in science. Calcutta University divided its B.A. into two branches—'A' course, i.e. literary, 'B' course, i.e. science. A fact of great significance, however, was that the entire direction of colonial education was not towards opening up the minds of students or developing a questioning attitude. Rather it encouraged passive acceptance of what was taught or written in the books. The books were in English and were mostly written and printed abroad. They depicted the British culture. Education so imparted, by and large, tended to alienate the educated people from their own culture. Further, the educational milieu ensured lack of enterprise, and readiness to take orders from above, which was indeed the intention of the rulers. Institutions and teachers looked at the British educational model as the ideal and, by and large, they tried to copy it even though they were in a very different social and economic situation.

SAQ 1

State, in the space given, whether the following statements about the scientific developments in colonial India are true or false. Write the correct answers for the false statements.

i) Botanical, geological and geographical surveys were carried out to map India's natural resources. ☐

ii) Research in physics and chemistry was encouraged to promote industrial development in India. ☐

iii) Some scientific societies came up and brought out some journals for disseminating scientific information. ☐

iv) Attention was paid to medicine only to serve the army and other British populace. ☐

v) There was a systematic and organised effort to solve problems in agriculture. ☐

vi) Several universities started offering courses in science education. ☐

vii) At school level, too, science education was given much attention. ☐

viii) The purpose of imparting education in British India was to create a spirit of free enquiry and innovative thinking. ☐

We have seen above, that the British were primarily interested in strengthening their political and economic domination over India. They exploited India's resources to the full and developed a nominal scientific infrastructure for this purpose. However, in all other areas, like physics, chemistry and agriculture, in which scientific development was not imperative, no attention was paid. In this period of colonisation, India's cultural heritage, scientific tradition and educational system got destroyed. In its place came a tradition of servility and an education that was designed to produce subservience rather than inculcate a spirit of free and creative inquiry.

The status of scientific research in colonial India was not much better. Let us see what it was.

7.2.1 Scientific Research in Colonial India

In the absence of higher scientific education, scientific research remained an exclusive governmental exercise for a long time. It was, therefore, linked to the economic policies pursued by the imperial power. A scientist serving the colonial power was supposed to not only discover new economic resources, but also to help in their exploitation. In agriculture, it was basically plantation research with emphasis on experimental farms, the introduction of new varieties, and the various problems related to cash crops. These were basically cotton, indigo, tobacco and tea, which were all to be exported to Britain. Next came surveys in geology to exploit mineral resources, again for export as raw material. Another major area of concern was health. The survival of the army, the planters and other colonisers depended on it.

In spite of difficult conditions and the government's lukewarm attitude, quite a few scientific works were carried out in this period. Ronald Ross did original work on the relation between malaria and the mosquito. Macnamara worked on cholera, Haffkine on plague and Rogers on kalazar. The famous medical scientist, Robert Koch visited Calcutta to work on cholera. Bacteriological laboratories were set up in Bombay, Madras, Coonoor, Kasauli and Mukteswar. This shift towards bacteriological research had one significant result. It led to the growth of clinical treatment, private practice and a booming drug industry. However, preventive measures like sanitary reforms, or even supply of drinking water to villages and towns remained neglected. In other fields too significant developments took place through the effort of foreign and Indian scientists working in institutions here.

The British activities did evoke some response from the local populace, particularly the educated section, who were looking for jobs in the colonial administration and economy. A few Indians participated in the officially patronised scientific associations or institutions. However, they often searched for a distinct identity and established institutions, scholarships and facilities of their own. Ram Mohun Roy's petition to Amherst asking for a proper science education became well known. Bal Gangadhar Shastri and Hari Keshavji Pathare in Bombay, Master Ramchander in Delhi, Shubhaji Bapu and Onkar Bhatt Joshi in Central Provinces, and Aukhoy Dutt in Calcutta worked for the popularisation of modern science in Indian languages.

Geography and astronomy were the areas chosen first because, in these fields, the Pauranic myths were considered the strongest. Vyas, the author of Srimad Bhagwat, for example, had talked about oceans of milk and nectar. This is part of popular myth even now, and this was attacked by these persons. For instance, Onkar Bhatt explained that Vyas was only a poet, not a scientist, and his interest was merely to recount the glories of God, so he wrote whatever he fancied. Even Urdu poets, devoted mainly to the romances of life, took notice of the western science and technology. Hali and Ghalib, for example, talked about the achievements of western civilisation based upon steam and coal power. The next logical step from these individual efforts was to give some organisational shape to the growing yearning for modern science.

In 1864, Syed Ahmed Khan founded the Aligarh Scientific Society and called for introduction of technology in industrial and agricultural production. Four years later, Syed Imdad Ali founded the Bihar Scientific Society. These societies gradually became defunct. In 1876, M.L. Sarkar established the Indian Association for the Cultivation of Science. This was completely under Indian management and without any government aid or patronage. Sarkar's scheme was fairly ambitious. It aimed at original investigations as well as science popularisation. It gradually developed into an important centre for research in optics, acoustics, scattering of light, magnetism etc. In Bombay, Jamshedji Tata drew up a similar scheme for higher scientific education and research. This led to the establishment of the Indian Institute of Science at Bangalore in 1909. There was, thus, greater awareness about science in India by the turn of the century. This was especially so, as a movement to gain freedom from colonial rule emerged. In the next section, we will discuss the impact of the freedom movement on the scientific developments. But before studying further, why don't you work out another SAQ ?

SAQ 2

a) State, in one or two lines, what the purpose for encouraging research in colonial India in each of the following areas was:

i) Botany

....

....

ii) Geology, Geography

....

....

iii) Medicine

....

....

b) Which one of the following statements describes the contributions of Indians to the scientific developments in the late nineteenth and early twentieth century? Tick mark the correct choice.

i) There was considerable organised effort in setting up societies, research and teaching institutes.

ii) There were some attempts here and there and some institutions were set up to promote original investigations as well as science popularisation.

iii) There were almost insignificant Indian contributions to scientific development.

iv) None of the above.

7.2.2 Impact of the Freedom Movement

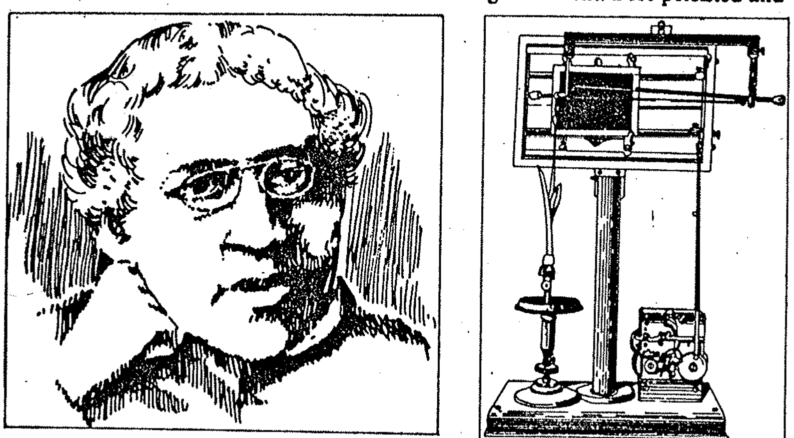
By the early twentieth century, the Indian society had started witnessing the first stirrings for freedom from colonial rule. While their political aspirations led to a demand for self-rule, the frustration resulting from economic stranglehold found expression in their insistence on using only goods made in India. This Swadeshi Movement provided further impetus for :

i) promotion of education along national lines and under national control with special reference to science and technology,

ii) industrialisation of the country.

In 1904, an Association for the Advancement of Scientific and Industrial Education of Indians was formed. The object was to send qualified students to Europe, America and Japan for studying science-based industries.

As mentioned earlier, in colonial India the environment was not conducive to higher studies, much less to research. Indians were allowed only subordinate posts and even those who had distinguished themselves abroad were given less salary than the Europeans of the same grade and rank. This 'apartheid' in science made the Indians react strongly. J.C. Bose, the first noted Indian physicist, refused to accept this reduced salary for three years. Not only this, till the Royal Society recognised Bose, the college authorities refused him any research facility and considered his work as purely private. J.C. Bose was unorthodox in one more sense. He was one of the first among the modern scientists to take to interdisciplinary research. He started as a physicist but his interest in electrical responses took him to plant physiology. To fight for a place and recognition in the scientific circles in Britain was no less difficult than fighting against the administrative absurdities of a colonial government. Bose persisted and won.



(a) (b)

Fig. 7.1: (a) J.C. Bose; (b) the crescograph, one of the many instruments invented by J.C. Bose, could record plant growth magnifying a small movement as much as 10,000,000 times.

Another noted Indian scientist, P.C. Ray had also suffered similarly. On his return from England in 1888 with a doctorate in chemistry, he had to hang around for a year and was finally offered a temporary assistant professorship. All through he had to remain in Provincial Service. P.N. Bose, preferred to resign, when in 1903 he was superseded for the directorship of the Geological Survey by T. Holland who was 10 years junior to him.

These problems were reflected on the political platform of the country. In its third session (1887), the Indian National Congress took up the question of technical education and has since then passed resolutions on it every year. K.T. Telang and B.N. Seal pointed out how, in the name of technical education, the government was merely imparting lower forms of practical training. The Indian Medical Service was also severely criticised. In 1893, the Congress passed a resolution asking the government "to raise a scientific medical profession in India by throwing open fields for medical and scientific work to the best talent available and indigenous talent in particular." Whether it be education, agriculture or mining, the Congress touched several problems under its wide sweep.

Fig. 7.2: Acharya P.C. Ray.

We find that the activities of this era had two important features. One was that almost all the exponents of Swadeshi looked to Japan as a major source of inspiration. Japan's emergence as a viable Asian industrial power and its subsequent military victory over Russia in 1904-05 caught the imagination of Indians. Another characteristic was that quite often they showed revivalist tendencies. This may have been because the distant past comes in handy for the recovery of a lost self or reassertion of one's identity. This search for moorings made P.N. Bose, a geologist, mention about whom has been made above, write *'A History of Hindu Civilisation'* in three volumes. J.C. Bose gave Sanskrit names to the instruments he had fabricated, like *Kunchanagraph* and *Shoshangraph*. Many science popularisers had a tendency to show that whatever was good in western science existed in ancient India also. For example, Ramendrasundar Trivedi's discussion on Darwin ends with comparing his theory with what is written in Gita. Later, B.K. Sarkar wrote on the Hindu Achievements in Exact Science.

Kunchanagraph is an instrument to show how plant body reacts to stimulus, by undergoing contractions. Shoshangraph is an instrument for studying absorption of water or any liquid by plants.

All these scientists were for the industrial application of modern science but failed to overcome certain cultural constraints, which was necessary for this effort. All they tried to do was to demonstrate that the Indian ethos and the values of modern science were congruent and not poles apart. In such a situation, it was not easy to evolve a correct understanding of our intellectual and cultural heritage. This was all the more difficult because of the total colonial domination both in education and in social life.

Fig. 7.3: Nobel Laureate C.V. Raman.

These efforts had, nonetheless, a galvanising effect. Taking advantage of the University Act of 1904, which allowed the existing Indian universities to organise teaching and research instead of merely affiliating colleges, Sir Asutosh Mookherjee took the initiative of establishing a University College of Science in Calcutta. Eminent scientists such as P.C. Ray, C.V. Raman, S.N. Bose and K.S. Krishnan taught there. This very college, although starved financially all through, produced a group of physicists and chemists who received international recognition. By contrast, the contributions of many government scientific organisations staffed by highly paid Europeans were rather poor.

Those who put India on the scientific map of the world were many. J.C. Bose showed that animal and plant tissues display electric responses under different kind of stimuli, like pricking, heat etc. We have referred to his work earlier also. S. Ramanujan, an intuitive mathematical genius contributed a lot to number theory. P.C. Ray analysed a number of rare Indian minerals and started the Bengal Chemical and Pharmaceutical Works, a pioneering and pace-setting organisation in the field of indigenous chemical and pharmaceutical industry. C.V. Raman's research on the scattering of light later won him the Nobel Prize in 1930. K.S. Krishnan did theoretical work on the electric resistance of metals. S.N. Bose's collaboration with Einstein on the study of elementary particles led to what is known as the Bose-Einstein Statistics. D.N. Wadia worked in the field of geology, Birbal Sahni in palaeobotany, P.C. Mahalanobis in statistics, and S.S. Bhatnagar in chemistry. Apart from the individual contributions of these scientists, their greatest contribution was in the field of teaching and guiding research. Many institutes were set up. For example, the Bose Institute (1917), Sheila Dhar Institute of Soil Science (1936), Birbal Sahni Institute of Palaeobotany etc. This gave further impetus to scientific activity in India.

Fig. 7.4: S. Ramanujan.

The need for an annual scientific meeting had been felt all along, so that different scientific workers throughout the country might be brought into touch with one another more closely. So far it had been possible only in the purely official and irregular conferences such as the Sanitary Conference or the Agricultural Conference. Thus, was born the Indian Science Congress Association (ISCA) in 1914 with the following objectives :

- to give a stronger impulse and a more systematic direction to scientific enquiry,
- to promote the interaction of societies and individuals interested in science in different parts of the country,
- to obtain a more general attention to the cause of pure and applied sciences.

The objectives have not changed much since then and the ISCA has now grown into the largest organisation of Indian scientists and technologists representing all disciplines of science and technology.

In the wake of the first World War (1914-18), the Government realised that India must become more self-reliant scientifically and industrially. It appointed an Indian Industrial Commission in 1916 to examine steps that might be taken to lessen India's scientific and industrial dependence on Britain. The scope of the resulting recommendations was broad, covering many aspects of industrial development. But few of the Commission's recommendations were actually implemented. Similar was the fate of numerous other Conferences and Committees. Whenever requests were made by Indians for starting new institutions or expanding existing ones, the government pleaded insufficiency of funds or inadequacy of demand. The interests of the colonial administration and those of the nationalists in most instances often clashed.

If we look at the events during the first quarter of the twentieth century, we find that this period was characterised by debate about further development. When Gandhiji started his campaign for cottage industries, varying notes were heard at the annual session of the Indian Science Congress. P.C. Ray, for example, held that general progress through elementary education and traditional industries, is a necessary pre-condition for scientific progress. But many differed with him. M.N. Saha and his *Science & Culture* group opposed the Gandhian path of economic development and supported setting up of big industries. The socialist experiments in Russia had unveiled the immense potentialities of science for man in terms of economy and material progress. The national leadership was veering towards heavy industrialisation and socialism, both of which stood on the foundations of modern science and technology. On Saha's persuasion, the then Congress President Subhas Chandra Bose agreed to accept national planning and industrialisation as the top item on the Congress agenda.

Fig. 7.5: S.N. Bose.

The result was the formation of the National Planning Committee in 1938 under the chairmanship of Jawaharlal Nehru. This Committee appointed 29 sub-committees, many of which dealt with such technical subjects as irrigation, industries, public health and education. The sub-committee on Technical Education worked under the Chairmanship of M.N. Saha. Other members were Birbal Sahni, J.C. Ghose, J.N. Mukherjee, N.R. Dhar, Nazir Ahmed, S.S. Bhatnagar and A.H. Pandya. The sub-committee reviewed the activities of the existing institutions to find out how far the infrastructure of men and apparatus was sufficient in turning out technical personnel.

The outbreak of the Second World War (1939-45) and the interruption of the direct sea route between India and England made it necessary for the colonial government to allow greater industrial capability to develop in India. It was, therefore, felt necessary to establish a Central Research Organisation and this was eventually followed by the establishment of the Council of Scientific and Industrial Research in 1942. As part of the post-war reconstruction plan, the government invited A.V. Hill, President of the Royal Society. In 1944, he prepared a report that identified various problems confronting research in India. These developments offered greater opportunities to Indian scientists in policy-making and management of scientific affairs. In fact, the origins of the science policy of free India and of the whole national reconstruction can be traced to these activities.

Fig. 7.6: Birbal Sahni.

Before you study further about the scientific developments in post-Independence India, you may like to attempt an SAQ to consolidate these ideas.

SAQ 3

Fill up the blanks in the following statements that summarise the impact of freedom movement on scientific developments in pre-Independence India :

i) An impetus for promoting science education and industrialisation according to national needs came from the .... movement.

ii) There were several notable contributions by individual .... However, the overall atmosphere did not encourage the growth of .... and .... in colonial India.

iii) The leaders of the freedom movement realised this and put forth a demand for raising the standards whether in education, ... mining or ....

iv) As the freedom movement intensified and scientific activity grew, there was a debate about further development. Eventually, the path of .... and national .... was chosen.

v) Committees were set up to review the activities of existing infrastructure, to identify the problems and to suggest ways of solving them. All these efforts formed the basis of the .... of free India and also of national reconstruction.

Fig. 7.7: M.N. Saha.

The foregoing analysis of British India illustrates that it was futile to expect the emergence of science here under an alien administration obsessed with one-sided commercial preferences. In such a situation, field sciences were developed to exploit natural resources and grow commercial crops; but a balanced development of research did not take place. When industry was not allowed to develop, many related sciences could not grow properly. As we have seen in Unit 6, an atmosphere of vitality and exuberance in the social and economic life was necessary to bring forth innovative ideas and to encourage scientific progress. Individual scientists, however, did shine in adverse circumstances. It was all the more so under the influence of a larger social movement and struggle, which promised to liberate and transform society. Thus, the situation changed when India became independent in 1947. Let us now discuss, in brief, the developments in science and technology in post-Independence India.

7.3 SCIENCE IN POST-INDEPENDENCE INDIA

When the Second World War ended in 1945, Germany, Italy and Japan had been defeated and France had been badly shaken. Even Britain had suffered tremendous losses and its economy was almost ruined. Thus, the colonial powers which had ruled the world and spread poverty, hunger and disease everywhere, were in no position to suppress people anywhere any more. The constant struggle for freedom in the colonial countries had also reached a high pitch. The result was that, one after another, more than a hundred countries of Asia, Africa and South America became free. The war had shattered the old system, and a new world had been born, with an entirely different set of opportunities and problems.

The countries which had become newly independent had the tremendous problem of reconstructing their economy so that tolerable conditions of living could first be created for all their people. The old ruling countries, on the other hand, had to think of ways and means of continuing to drain the wealth of their erstwhile colonies. This was necessary to enable their business enterprises to continue making high profits so that they could maintain relatively high standards of living to which their own people had become accustomed.

Science and technology had to be deliberately employed by both sets of countries. The only difference was that the developing countries had to make a start from scratch—with hardly any institutions or people who could engage in competitive science and technology, whereas the advanced or developed countries now had a stronger base of science and technology than ever before. During the war great sums of money had been spent on developing nuclear science and the atomic bomb, on electronics as applied to radar and communication, and on advanced designs of aircrafts, submarines and other means of waging war. All other sciences were also in a much better position than before. This base of science and technology was to be used to the advantage of developed countries to regain the old glory and power. In other words, our struggle for "development" and their struggle for supremacy are two sides of the same coin. Science and technology play a pivotal role in this international competition.

The Indian freedom movement had been conscious that political independence was only a stepping stone to economic independence. Our leaders had realised that our decisions about industry and trade would have to be taken by us alone without compulsion of foreign governments or their business counterparts. And that our economic development would have to serve the people and meet the minimum needs of their food, health, shelter, education, culture etc. For this, we could not leave economic development to chance, or to the purely profit motive on which private industry and trade operate, their natural tendency being to produce what can sell, rather than what is needed in our social context. Therefore, an essential part of our approach to development was to plan our economy to bring about maximum human satisfaction combined with growth.

The role of science and technology was crucial for this endeavour and this was clearly expressed in the "Scientific Policy Resolution" adopted by the Parliament in 1958. This resolution was drafted and piloted through the Parliament by our first Prime Minister, Jawaharlal Nehru. In the words of this Resolution :

"The key to national prosperity, apart from the spirit of the people, lies, in the modern age, in the effective combination of three factors, technology, raw materials and capital, of which the first is, perhaps, the most important, since the creation and adoption of new scientific techniques can, in fact, make up for a deficiency in natural resources, and reduce the demands on capital. But technology can only grow out of the study of science and its applications."

Since Independence, and particularly after the passage of the Resolution, a great expansion of science and technology in both education and research has taken place. The situation today is far different from what it was in 1947. We have now about 200 universities including 6 Indian Institutes of Technology, over 800 engineering colleges and 110 medical colleges, a few hundred scientific research laboratories under the Central and State governments, as also R & D units in private industry. Research is being done in almost all areas of modern science. The conspicuous success of our scientists in atomic energy, space research and agriculture is well known.

The funds allocated to research have also vastly increased over what they used to be 40 years ago. But in the modern world, it is not enough to be in the forefront of creative science or innovative technology. Out of the total world expenditure on research, excluding the socialist countries, 98% is spent by the developed countries, the old imperial powers. Only 2% is spent by all the developing countries taken together. In this, India's share may be half a per cent. Moreover, since the developed countries have better facilities, better opportunities for scientific world and higher standards of living, a fairly high proportion of our talented young people migrate to those countries. They are, thus, unable to contribute towards national development by solving our problems through science and technology. New discoveries and new inventions, therefore, still come from the advanced or developed countries. This position does not seem likely to change in the near future.

A new feature of the world since the Second World War is the armaments race. It started with the Americans dropping the radically different weapon, the atom bomb, on Hiroshima and Nagasaki in Japan. Since then, modern bombs, each equivalent to a million tons of the old explosive, were developed both by the U.S., the then Soviet Union and other nuclear powers. Nuclear powers have missiles which can carry the bombs to targets half way round the globe. Each offensive weapon has led to a new defensive system. There has also been a race to obtain bases in other countries. A dangerous aspect about nuclear weapons is that these could be triggered off even by mistake, and could destroy all civilisation. Thus, we can see that the security of neither of these countries has improved. In fact, many other countries are drawn into the race because weapons of one country have to be matched by another. It is calculated that the world is spending more than 1,00,000 crore rupees per year on armament and the developing countries are spending about 20% of this amount, much of which goes to buy weapons from firms in the developed countries.

Imagine such a lot of money, representing human labour, being wasted year after year. Naturally resources for development are diverted to "security". On the other hand, people in underdeveloped countries are still largely illiterate and deficiently served in basic requirements of life, such as food, drinking water, medicine etc. Interestingly, it is said that the arms race has led to huge profits being made by a small number of firms, and it is designed to suck away the resources of developing countries so that their dependence on foreign loans, technologies and strategic policies is increased. The more sophisticated the weapons are, the more is our dependence on the advanced countries.

Surely, this is neither a happy situation nor a stable one. The power of science has reached such a pitch that international relations have to be readjusted, and national effort has to be recast so as to bring the benefits of science to the lives of common people.

We now end this discussion with an SAQ for you!

SAQ 4

Tick mark the three statements that reflect the efforts of our country in solving our problems with the help of science and technology.

i) Adopting a carefully formulated science policy. ☐

ii) Allowing young scientists to migrate to developed countries. ☐

iii) Expansion of science and technology in both education and research. ☐

iv) Increased research funding. ☐

v) Diverting resources, for buying weapons. ☐

7.4 WHAT WE HAVE LEARNT

What we have discussed so far in Blocks 1 and 2 leads us to underline the following points about the use of science and technology in our social context.

i) Knowledge is one, and its various components such as physics, chemistry, biology, medicine, technology, economics etc. are profoundly inter-related. However, we have become accustomed to separating the study of science from that of social sciences and humanities. This may be explained by historic circumstances as we have mentioned in Sec. 5.2.1 and Sec. 6.4.1, but it is an undesirable feature of the present educational and research system. It does not allow a person to have a unified view of how the components interact, or more particularly, how science plays a role in changing the socio-economic system and how the socio-economic plans and policies affect science.

For many years, scientists believed that science is good in itself. This continued until the sociologists pointed out how science can be destructively used, how diseases can be spread rather than controlled by science, how aeroplanes and even the modern space science can be misused to wage wars for subjugating people or even killing them on a massive scale. For science to be good, it must be designed to help in serving the purpose of uplifting and improving the human condition.

ii) We have seen in Unit 6 that much of the modern scientific and technological development has taken place in the context of, and according to, the demands of the West European society, and, later, the American society. We should carefully examine if all the ideas developed there suit our Indian society. For example, practically all mechanisation was to increase productivity of labour, or, in practical terms, to have more production from fewer people. This is a labour saving outlook, fit for a country where labour was in short supply—as in the European countries. What would be the effect of mechanisation on the employment situation in a populous country like ours? Mechanisation as an exact copy of what happened in the western world may not be in our best interest, unless employment and the related buying power of the people is ensured.

Mechanisation and modernisation may reduce the labour cost of production and hence profits may increase, but the social costs may become unbearable in a country in which the majority of population is poor. Obviously, a careful and cautious policy is needed. A concrete example is in agriculture: non-mechanical agriculture typically produces 5 to 10% surplus so that the population in the towns can be fed. Mechanisation does not increase the yield from soil. What happens is that only fewer people, say 5%, can produce the entire needed surplus. But then what would the rest of the rural population do? If they are unemployed and made poorer still, they may not be able to buy the food which is produced. The answer is to open up other avenues of employment. It means that careful and many-sided planning is necessary to take real advantage of mechanisation in agriculture or in industry.

iii) Another disputable idea is that of "efficiency" of an enterprise, say, a factory. As we have seen in Unit 6, historically, maximising profit was the only concern of the factory owner. Therefore, he made an analysis of the inputs to the production system and the outputs. Social concerns did not figure in his scheme of things. For instance, some factories set up on the basis of 'high efficiency' have led to terrible pollution of the environment, with smoke and soot and all kinds of dirty stinking or acidic water coming out of the factories and stagnating around them. We see such a situation in India even now when we have not reached as high a degree of industrialisation as in the West. In Europe or America, where industrialisation was even more intense, whole cities like Birmingham in U.K. or Chicago and Detroit in USA had become black, often covered with smoky fog. Similarly, scarce resources from the earth were mined and sold for a handsome profit without caring either for degradation of the soil or depletion of the resources in the long run. Thus, with the so called 'efficiency' related only to the profit that one could make, social problems were often made more acute. We cannot afford to further complicate our problems by uncritically using an idea, approach or a definition from the developed countries.

iv) There are many other ideas which would need to be scrutinised and modified before being accepted for our conditions. One is "economy of scale", which means you can make more profit if you produce goods on a large scale, since the overhead costs do not increase proportionately. This idea was good in the past when markets, particularly in the colonies, and export markets were more freely available to the industrialised countries. Today, the social needs, howsoever limited, will have to be taken into account. For instance, in our context, men and machines should be producing what is urgently needed by our own people. Gearing production to an export market, even if one were available, at the cost of our own needs, is not an unmixed blessing.

v) Another misconception that people have is that science and technology are freely available to all who care to use them. Unfortunately, technology and the most advanced ideas in science are used to produce goods which are sold either at exorbitant prices or to bargain for concessions of another kind. You may have read in the newspapers about defence equipment, "super computers", and other sophisticated technology being offered to developing countries under all kinds of conditions. Technological secrets are the most jealously guarded secrets in the present world. Even scientific advances made by laboratories in the developed countries are withheld for as long as circumstances would allow.

Thus, we can see that even after the colonies have gained their independence, the colonial yoke has not completely gone. Science and technology are being used as tools to make developing countries behave more or less according to the interests of the developed countries. We will resume this discussion in the last block of this course and explore how we can use science and technology for the national good.

7.5 SUMMARY

In this unit, we have dealt with the developments in science in colonial and post-Independence India. The newly industrialised countries had in their search for raw materials and markets for finished products, colonised many Asian and African countries. India came under the British colonial yoke. This influenced the subsequent scientific developments in India. Let us now summarise the main features of this unit :

- The colonisers were interested only in exploiting India's natural resources. Thus, developments took place in a few areas like botany, geology, geography etc. However, the long standing Indian tradition of science was destroyed. All creative thought was sought to be stifled by the colonial masters to keep the Indians backward.
- The local populace responded by setting up institutions of their own that worked for the popularisation of science. The freedom movement gave further impetus to this cause. Several Indian scientists received international recognition for their work. But, above all, there emerged a conscious thinking about using science and technology for the benefit of all our people.
- This was reflected in the policies adopted by our country after gaining independence. Several steps were taken to effectively use science. Yet, there are still several aspects which need careful attention. Notable among these is applying western ideas and approaches to our problems regardless of our social milieu. We have also to fight against the tactics of the developed countries to dominate us by withholding scientific or technological information, embroiling us in the arms race etc. We have yet to go a long way in attaining the standards of the developed countries.

7.6 TERMINAL QUESTIONS

1) State, in four or five lines, why there were such few developments in science in British India.

....

....

....

2) List two aspects of the role of developed countries, which impede our development in science and technology.

....

....

....

....

....

....

3) Which three options from among the following would you expect our country to exercise for using science and technology in our social context? Tick your choices.

i) Increasing the funding of education and research. ☐

ii) Preventing brain-drain, i.e. the migration of young scientists to developed countries by creating favourable conditions. ☐

iii) Leaving economic and scientific development entirely to private enterprise. ☐

iv) Encouraging an all-round education in the various components of knowledge. ☐

v) Adopting uncritically, the ideas or practices of the developed countries. ☐

7.7 ANSWERS

Self Assessment Questions

1) i) T ii) F iii) T iv) T v) F vi) T vii) F viii) F.
ii), v), vii), viii): It was just the opposite for each case as you can see from the text.

2) a) i) To solve the problems of introducing new varieties of cash crops like cotton, tea, indigo for export to UK.
ii) To exploit mineral and natural resources.
iii) To provide healthcare for the colonisers.

b) ii)

3) i) Swadeshi
ii) Scientists, science, technology
iii) agriculture, medicine
iv) Industrialisation, planning
v) science policy

4) i) ✓ ii) × iii) ✓ iv) ✓ v) ×

Terminal Questions

1) The primary aim of the colonisers was to maximally exploit India's natural resources for supplying raw materials to Britain and sell finished products in the Indian market. They were just not concerned with preserving India's scientific and cultural tradition or encouraging any development, scientific, educational or material in India.

2) i) Use of science and technology to assert their domination over underdeveloped countries and to make them behave.
ii) Encouraging the arms race so as to make huge profits and increase the dependence of poor countries on loans, technologies and strategic policies.

3) i) ✓ ii) ✓ iii) × iv) ✓ v) ×

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.

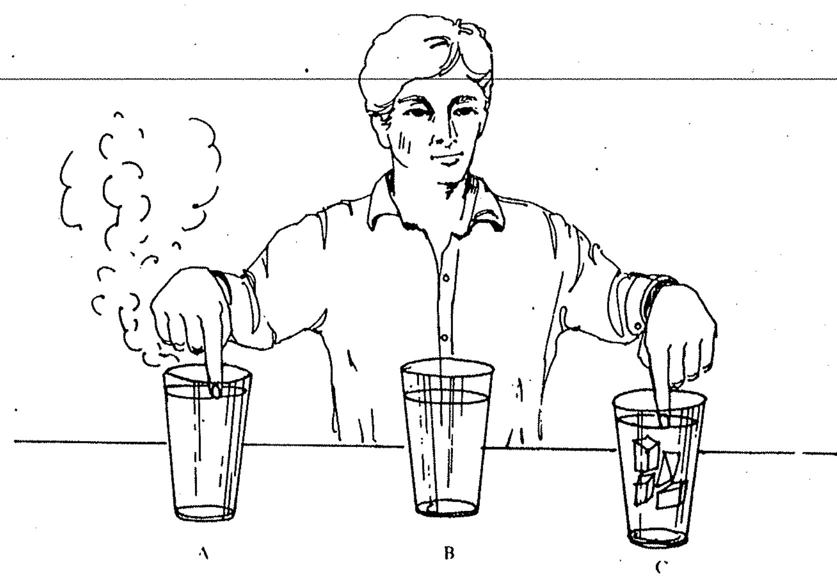


Fig. 8.1 : If you put a finger of one hand in hot water (glass A) and a finger of the other hand in cold water (glass C) for some time and then put them both in lukewarm water, you will find that the two fingers feel different sensations. The water in the glass B appears warm to the finger that was in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

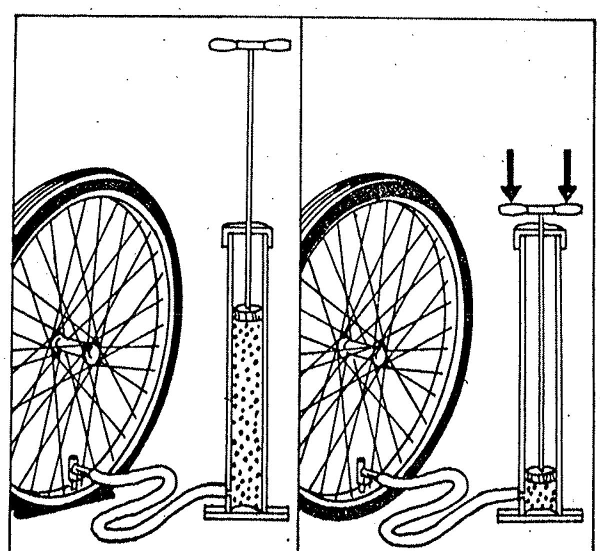


Fig. 8.2: Compression of air by decreasing its volume in a bicycle pump.

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.

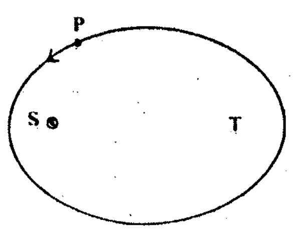
Apparatus

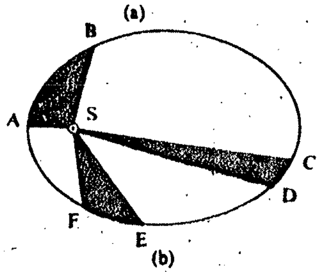
Scientists use various kinds of instruments for observation and experimentation. Instruments like telescopes, microscopes or microphones can be used to extend or make more precise, the observations made through senses. Scientists also use instruments to manipulate things or phenomena in a controlled 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





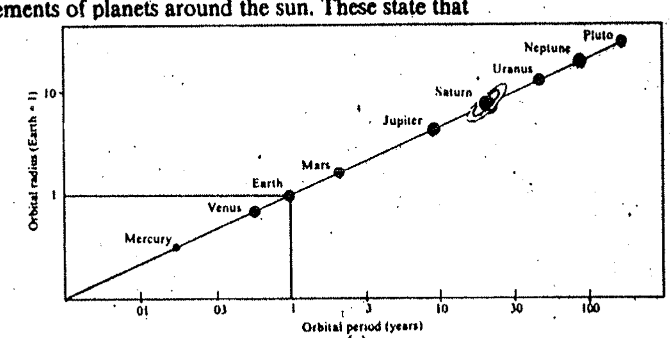


Fig. 8.3: Kepler's laws of planetary motion. (a) First law: a planet (P) moves in an ellipse with the Sun (S) at one of the two foci; (b) second law: It takes as long for a planet to travel from B to A and from F to E as from D to C; the shaded areas ASB, ESF, CSD are all equal; (c) third law: The size 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.!

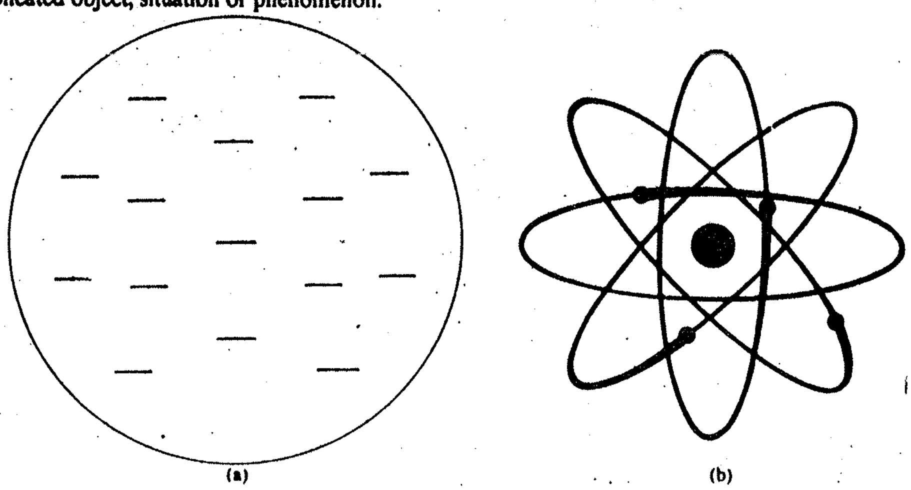


Fig. 8.4: (a) Plum pudding model of an atom. The negative charges are embedded like plums, in a positively charged sphere (shaded area). (b) the atom modelled after the solar system.

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 :

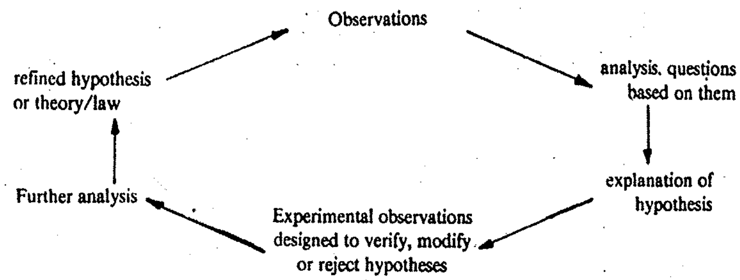


Fig. 8.5: The method of science.

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.

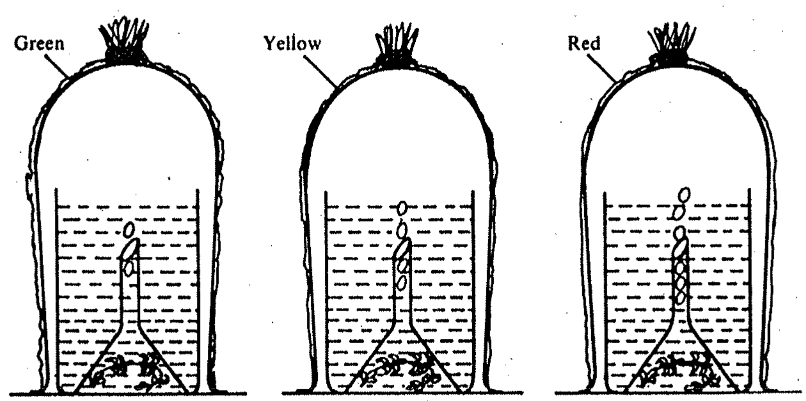


Fig. 8.6: An experiment to test whether light of a specific colour is more effective than light of other colours for photosynthesis.

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.

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.

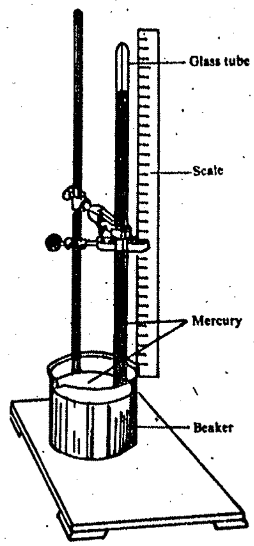


Fig. 8.7: Barometer.

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.

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.

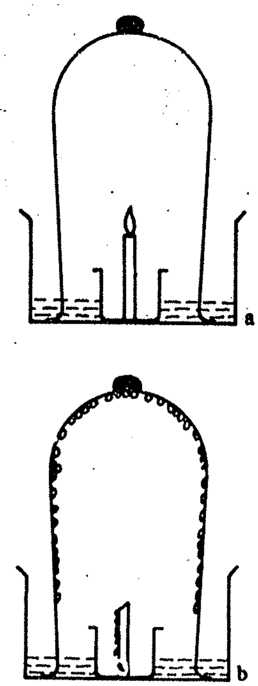


Fig. 8.8: Verification of the law of conservation of mass.

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.

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 chil ....

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?

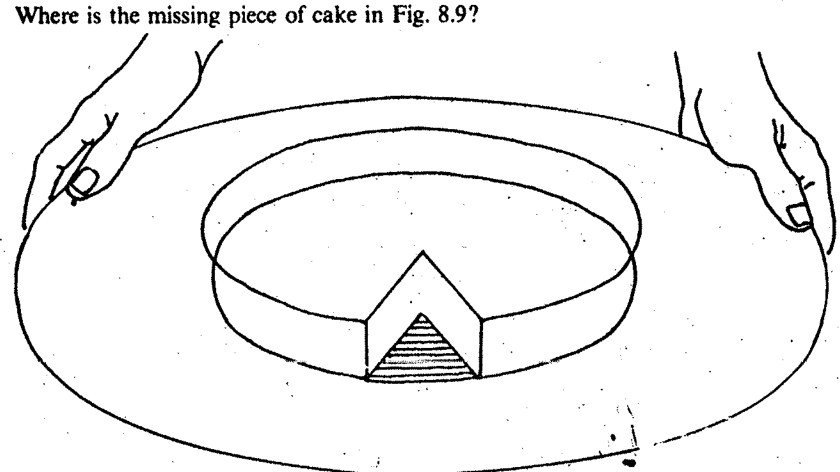


Fig. 8.9

....

....

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

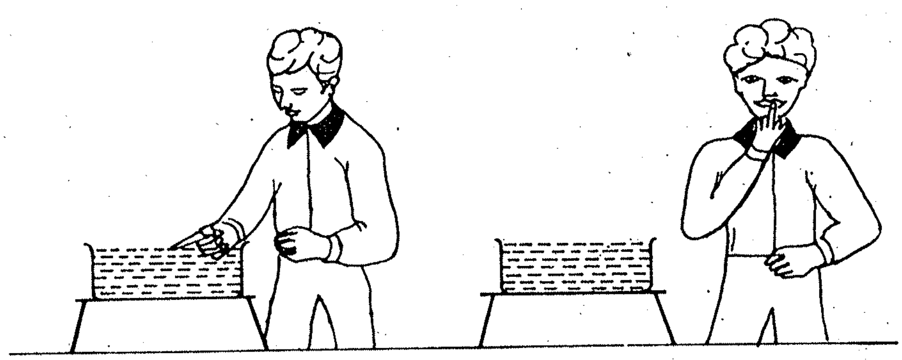


Fig. 8.10

....

....

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

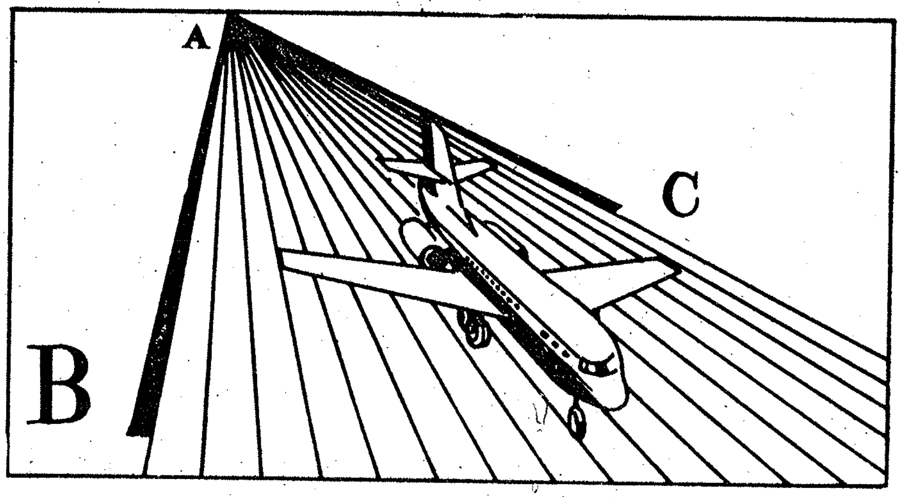
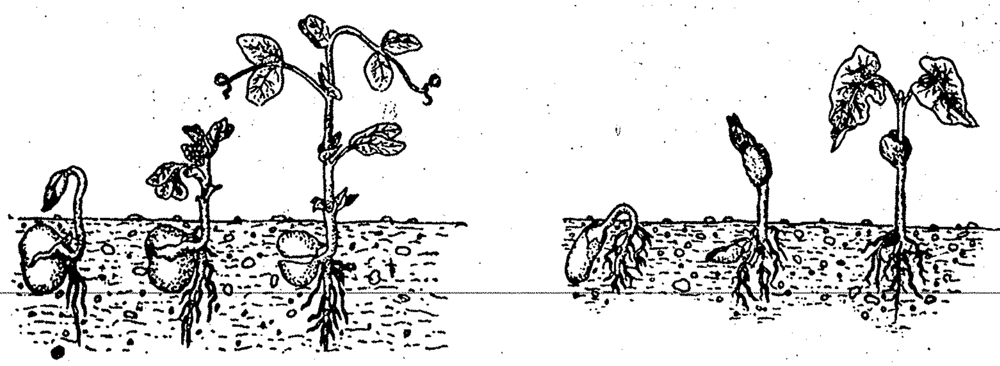


Fig. 8.11

....

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.

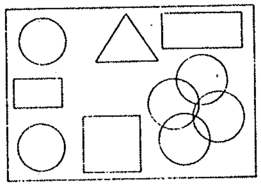


Fig. 8.13

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.

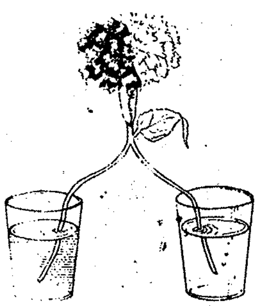


Fig. 8.14

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.

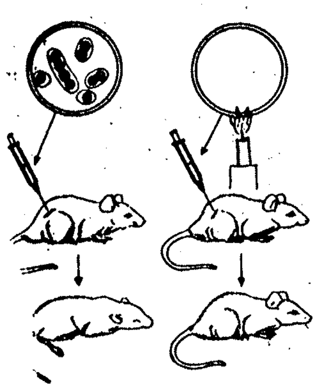


Fig. 8.15

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

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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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4) Evolution of Man (Block 3)
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Notes