UNIT 4 THE GOLDEN AGE OF SCIENCE IN INDIA

Structure

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4.1 INTRODUCTION

In Unit 3, we have described the development of science in India until the fourth century B.C. You have seen how, in this period, the growth of science was helped by the emergence of urban societies. You will now read about one of the most productive periods in the history of science, in India. This period started roughly around the fourth century B.C. and lasted for about eleven centuries. In this period, forest land in northern India was cleared, paving the way for settled agriculture. Trade and commerce prospered as small kingdoms gradually gave way to great empires. The empires established uniform laws and practices which prevailed over a great land mass. A state which looked after its subjects arose and India settled for a period of peace and prosperity which continued until the seventh century A.D.

This was a period of great developments in science, in India, especially in astronomy and mathematics. This was also the period of Buddhism and Jainism, the great liberal theologies. But these theologies declined towards the later part of this period, giving way again to rigid Hindu caste structure. The struggles and debates related to these religions left a lasting impression on the development of science. Science finally started to decline as the empires broke up into small feudal kingdoms, but, fortunately, not before the great Indian scientific tradition was passed on to the Arabs. The Arabs made their important contribution to science and India received it in later ages. You will read about Arab contribution to science and about science in medieval India, in Unit 5.

Objectives

After studying this unit, you should be able to :

- explain the features of the Indian state and the social organisation that helped the growth of science and technology in the Maurya and Gupta periods,
- describe the developments in science and technology in India, from the fourth century B.C. to the seventh century A.D.,
- outline the factors that led to the decline of science in India by the seventh century A.D.

4.2 SECOND URBAN CIVILISATION IN INDIA

We have already mentioned in Unit 3 that, of the sixteen Janapadas in the seventh century B.C , Magadha had emerged as the major power (see Fig. 3.4). Thus, the stage was set for a second urban civilisation to flourish in India, after the decay of the Harappan Civilisation more than a thousand years ago. This second phase can be dated back to the advent of

Chandragupta, the great Maurya king in the fourth century B.C. The last great Mauryan emperor, Asoka, assumed the imperial throne about 270 B.C. His empire extended across the whole of northern India and well into the southern state of present-day Karnataka (Fig. 4.1).

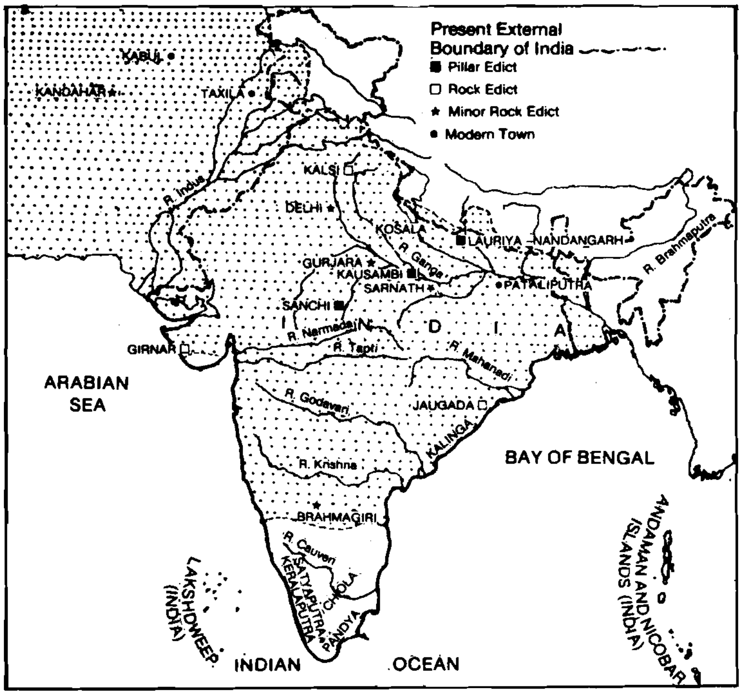
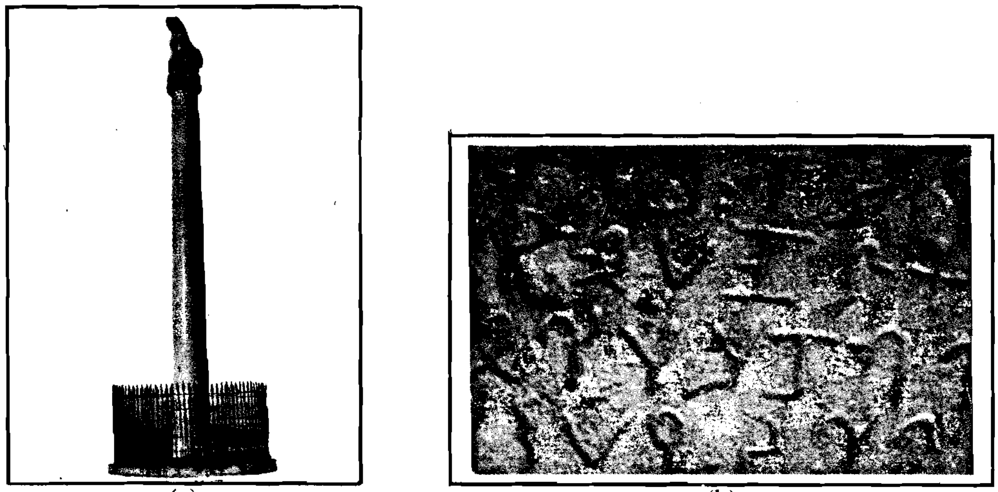


Fig. 4.1: Empire of Asoka (about 274—236 B.C.).

The imperial state was mainly interested in extending its hold on cultivable land. It acquired tribal land by conquering small kingdoms. The local population of the conquered lands settled down to practise agriculture under the supervision of imperial functionaries who were often Brahmins. They started using new techniques which were introduced at that time. There were two types of agricultural land. The first type, which yielded taxes for the state, had a semi-autonomous local administration, although a sixth portion of the harvest went to the crown treasury. The second type, called *sita* land, came directly under crown supervision and was cultivated by settlement units of 100 to 500 *Sudras*. They gave a fifth of their produce to the crown. These did not include a tax for "army rations" and gifts to the king.

The acquisition and maintenance of land on such a large scale required a well trained army, an ideological and religious superstructure, good agricultural base and mining industry. And above all, it required a centralised state power which could hold together and expand such heterogeneous empire. Let us see what the nature of the socio-political organisation of state power in the Mauryan empire was (see Fig. 4.2).



(a) (b)

Fig. 4.2: A great deal of information about Asoka's policies and his times comes from his inscriptions engraved on rocks, on polished stone pillars and in caves, in Kharosthi script. In Kandahar, they are written even in Greek script and in Greek language. (a) Asokan pillar at Lauriya–Nandangarh; (b) a stone inscription of Asoka's times.

4.2.1 The Indian State

Such a state and its policy is described in detail in Arthasastra, written by Kautilya, the great minister of Chandragupta. According to him, it was a highly centralised state which was the principal owner of industry as well as the greatest producer of commodities. The commodities produced by the state were bought and sold by traders. The traders travelled across the empire, often using navigable rivers, and even went overseas to Burma, Indonesia and Sri Lanka to sell their wares. Trade practices and the prices charged by traders were strictly controlled by the state. Laws regulating revenue collection, and the procedures for collecting them, from the land as well as from the merchants, were exact and precise. This large revenue was used to maintain a massive army, of half a million men, which was used to acquire land, protect the land and the frontiers, and maintain law and order in the vast empire. The revenue was also used to organise welfare measures for orphans, the aged, the infirm, widows and pregnant women who had no one else to feed them.

Now the army could conquer land, but, it could not ensure that the conquered people would voluntarily and peacefully serve the empire and make it prosper. We find that the state used religion in an extremely intelligent fashion to achieve this.

Brahmins, as agents of the crown, spearheaded the move into the new territories. A process was initiated whereby tribal deities were equated with standard Aryan gods. New scriptures were written by Brahmins to bestow respect on tribal gods whom they could not otherwise adopt. New rituals and special dates of the lunar calendar were introduced, which took account of the tribal customs. Totemic deities such as primaeval fish, tortoise, monkey, bull etc. were introduced into the traditional Hindu scriptures as companions of major gods like Vishnu, or their reincarnations. Further, ideas were propagated that tribal chiefs were also twice born (*dwija*), which gave them special high caste status. A caste structure was, thus, subtly introduced whereby the ruling elite of the tribals were incorporated into the ruling hierarchy of the empire. All this amounted to assimilation of the tribal hierarchy into the more accentuated caste-class structure of the empire. The *Vaisyas* and *Sudras* newly created in the tribes, joined the lower-caste community of the peasants and workers of the empire without an apparent break of their own traditions, culture and religion.

The *Brahmins* could impose the caste structure quite easily, as they played an important part in introducing a new mode of agriculture and of commodity production to the tribal people. They brought plough agriculture to replace slash and burn cultivation or food gathering. New crops and knowledge of distant markets brought by the Brahmins, gave visions of higher productivity and prosperity to the people.

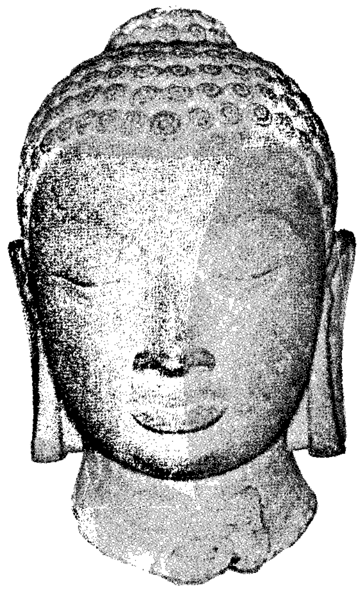
These developments had a profound effect on production from land and united the people culturally for peaceful living. The developments also increased the wealth of the state. However, the new religion which evolved over a period of time, started to inhibit the growth of culture as well as production. This was because it laid emphasis upon superstitions, which were very much a part of tribal life, and on senseless rituals. The superstitions, which provided the ideology of the lower castes, in effect, kept them in subjugation. Finally, these superstitions came to have an adverse effect on the growth of scientific ideas.

It is not surprising that Asoka reacted to the development of this superstitious and ritualistic culture by adopting the teachings of Buddha. Buddhism, in its early form, devoid of rituals and superstitions, stood against oppression and advocated a simple and meaningful life based on reason and compassion (Fig. 4.3).

Asoka and the later Indian kings provided generous grants to the Buddhist monasteries which supported learning and science. Nalanda, the great Buddhist monastery was the forum where scholars continuously met and exchanged ideas on medicine, astronomy, humanities and theology. The Indian imperial state continued to support the monasteries for a long time.

Monasteries, thus, became wealthy institutions and provided funds and capital to traders. With time, the ascetic simplicity of Buddhism came to be replaced by a more ritualistic religion. While Buddhism provided an initial challenge to the rigid caste laws of the Hindus, Hindus possibly had the last say. For, Buddhist religion, in order to gain popularity, increasingly adopted the ideological as well as the ritualistic practices of the Hindu religion of those days.

We have described above, the economic and political scene of the Mauryan empire in some detail, as the character of this development greatly influenced the application of science. We will now describe, in brief, some developments in technology. But before that, how about answering an SAQ to test yourself !



(a)

Believe nothing
merely because you have been told it
Or because it is traditional
Or because you yourself have imagined it
Do not believe what your teacher tells you
merely out of respect for the teacher
But whatever after due examination and analysis
you find to be conducive to the good
the benefit,
the welfare of all beings,
that doctrine believe and cling to
and take it as your guide.

(b)

Fig. 4.3: (a) Image of the Buddha, Gupta period, 5th century A.D.; (b) teachings of Gautama Buddha. Note the scientific approach in his sayings.

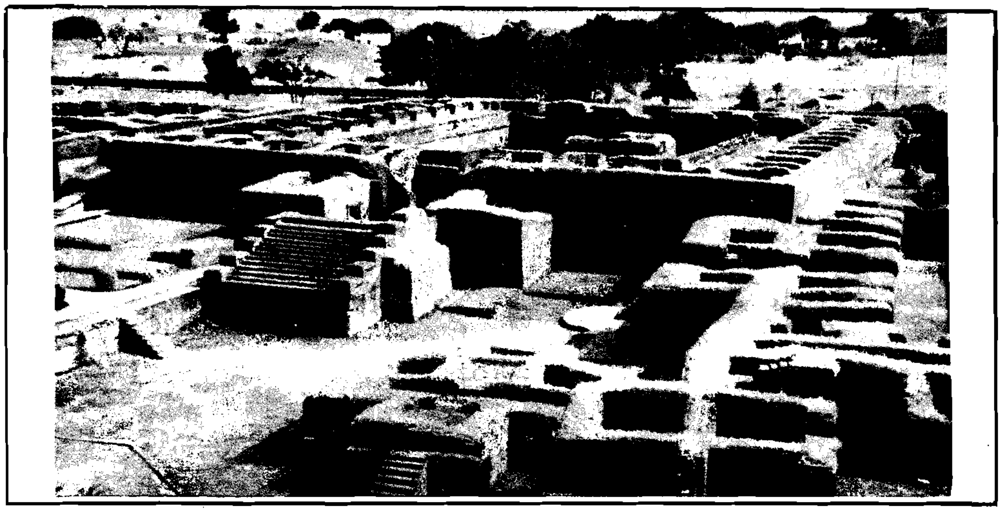


Fig. 4.4: Nalanda, a view of monasteries.

SAQ 1

Which five mong the following statements reflect the socio-economic needs of the rising Mauryan empire that led to the technical developments of those times? Tick the correct choices in the boxes provided alongside.

i) Large scale acquisition and maintenance of land.

ii) Emergence of a centralised state power.

iii) Maintenance of a large well trained army.

iv) Trade within the empire and with foreign lands.

v) Formation of laws for revenue collection.

vi) Development of agriculture and mining industry.

vii) Emergence of an ideological and religious superstructure.

4.2.2 Developments in Technology in the Mauryan Empire

We get a great deal of information about the technical developments in the Maurya period from the treatise, Arthasastra. In Arthasastra, there are detailed descriptions of military machines which use the principle of centrifugal forces. However, the ideas to power these machines with inanimate sources such as wind, water, steam or electricity, did not exist then.

There was considerable development in civil engineering. For increasing the productivity of *sita* land, many forms of irrigation came to be used. Excellent roads were built throughout the empire to facilitate mobility of the army and the traders. Corduroy roads were built over swamps using trimmed logs. For example, in Bihar, such roads ran for miles even in the

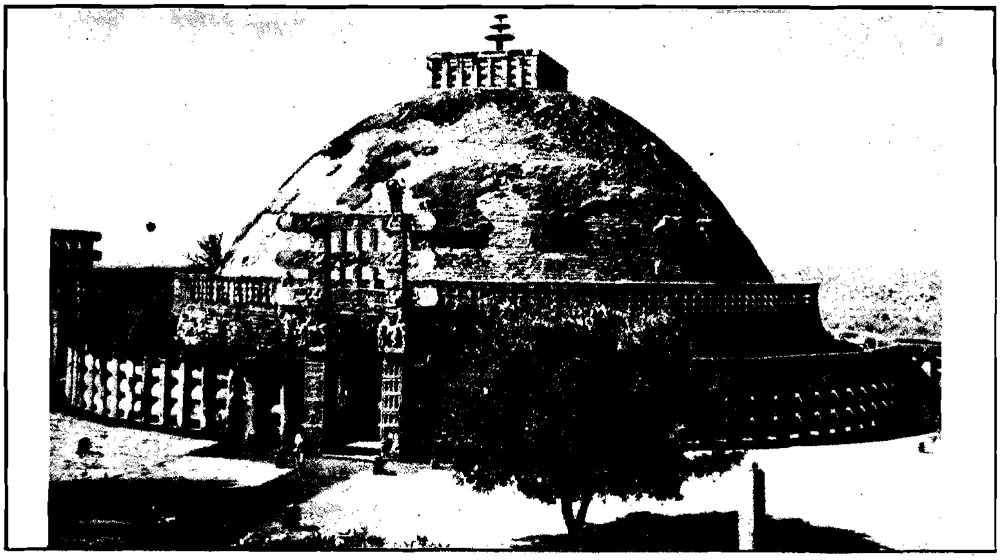


Fig. 4.5: General view of Sanchi Stupa. Notice the intricate workmanship on the pillars which speaks volumes about the human artistry and skill of those times.

seventh century A.D. Most of the buildings were made of wood. Asoka, possibly for the first time in India, introduced stones to construct buildings. Stones were polished to a mirror-like finish and used for the construction of pillars and arches (Fig. 4.5).

There was some development of rural industries also. Small industries and relevant technology came into being near the *sita* lands for husking of grain, pressing of oilseeds, carding of cotton and wool, spinning of yarn, grading and processing of wool, manufacture of blankets and shaping of timbers into planks and beams. The concept of factory production took shape, probably for the first time, as the above commodities were produced under the direct supervision of the superintendent of the "crown store houses". Local labour was seasonally engaged, when agricultural operations were slack. The books showed meticulous recording of normal loss of every kind of material at each state of processing, average output of efficient labour, final weight or measurement of the finished product etc. These records were used to control production.

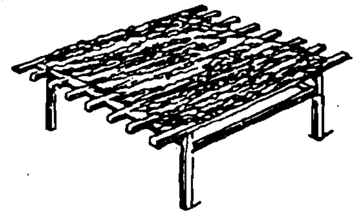


Fig. 4.6: Arthasastra mentions many rural industries such as carding of wool. Carding was a scraping process applied to lower-grade wool. Spreading the wool on wicker frames, workers untangled it with wire scrapers.

The greatest contribution to the advancement of technology was, perhaps, made in the area of metallurgy and metal working. The shifting of the seat of power from the north-west to Magadha, was mainly due to the increasing demand for iron, copper, tin, lead and other metals. The metals were needed for making weapons and ploughshares, the two essential pillars of the Mauryan state, as well as for manufacturing other goods of trade. There are careful, though brief, descriptions in the Arthasastra for reducing and smelting ores. Distinction between different ores, in terms of their appearance and other properties, and the corresponding distinction in processing techniques are elaborated. Metallurgy of making alloys was also developed. The finest of iron ores from different parts of the empire, especially the south, were brought for making alloy steels. Swords made from these alloys were sold in many countries, including Greece.

SAQ 2

We are listing below some of the needs of the Imperial State. Indicate against each statement, the technical innovations that accompanied each of these :

a) Better mobility for the traders and army.

....

b) Increasing the productivity of land.

....

c) Processing agricultural products to make articles for consumption and trade.

....

d) Making weapons and ploughshares.

....

We, thus, find that in certain areas like rural industries, civil engineering, metallurgy and mineral engineering, there were remarkable advances in the Mauryan empire. We shall now see what was happening in the other parts of India, especially in southern India in this period.

4.2.3 Developments in South India

Asoka's reign was followed by a fragmentation of the empire into small kingdoms, torn by bitter rivalry. The next major empire to emerge was that of the Kushanas. This empire, which dates back to the first century B.C., incorporated regions not only of northern and north-western India but also of Central Asia and what are now Pakistan and Afghanistan. Under the reign of Kanishka (second century A.D.), the empire extended east as far as parts of Bihar and into central India as far as the river Narmada. In southern India, a few powerful kingdoms of Satavahanas, Kshatrapas and Vakatakas came into being at about this time.

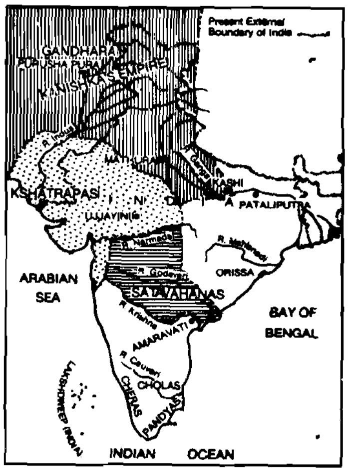


Fig. 4.7: Various empires in India, about 150 A.D.

This was one of the most flourishing periods in the history of crafts and commerce in southern India. The inscriptions of the period mention weavers, goldsmiths, dyers, jewellers, sculptors and workers in metal and ivory, indicating that these crafts were well developed. Iron tools and artefacts like ladles, razors, axes, hoes, sickles, ploughshares etc. have been found in the Karimnagar and Nalgonda districts of the Telangana region of Andhra Pradesh (Fig. 4.8). Coins of lead, copper, bronze, silver and gold have also been found. Many of these are from Satavahana period indicating the progress they had made not only in the metallurgy of iron, but also of brass, zinc, antimony etc. Cloth making, silk weaving

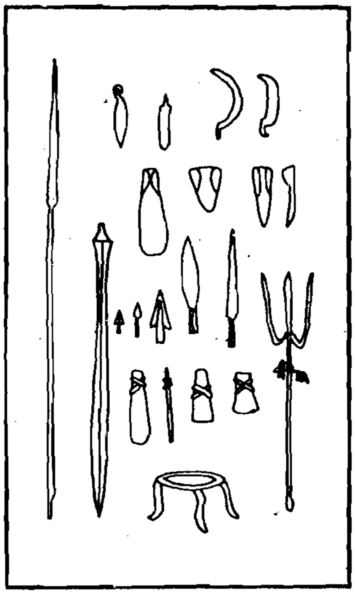


Fig. 4.8: Iron tools and other objects from the graves at various sites in South India. Note the sickles and daggers, axes, arrow-heads, spear-heads, spear, sword, trident, and the tripod.

and making of luxury articles of ivory, glass, beads etc. was also developed. Dyeing was a thriving craft in some south Indian towns. Brick built dyeing vats, dated first to third century A.D., have been excavated at Uraiyur and Arikamedu in Tamilnadu. The production of oil increased because of the use of oil wheel.

Extensive trade was carried out by sea. The knowledge that monsoons aided sailing, greatly helped the sea-faring traders. Iron and steel articles, including cutlery, were exported to African ports. Muslin, pearls, jewels, precious stones and spices were exported to Rome. This thriving trade led to the prosperity of Satavahana towns.

However, these empires declined from the third century onwards. The great age of the Indian empires reached its peak with the advent of the Gupta dynasty, at about the beginning of the fourth century A.D. We will now describe the social organisation in the Gupta period and see how it helped the growth of science and technology, in India, in those times.

4.3 THE GUPTA PERIOD

The Gupta empire expanded most in terms of its territorial coverage of northern, southern, eastern and western India as well as in terms of cultural development during the reign of Chandragupta II (380–415 A.D.) (see Fig. 4.9). It is worthwhile that we should consider a few characteristic features of this period of about 100 years. You will then be able to understand the development of what may rightly be called the peak of the Golden Age of science in India.

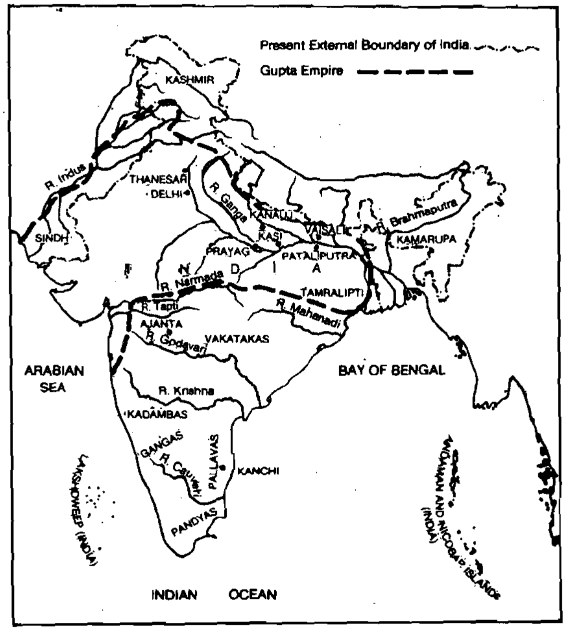


Fig. 4.9: Gupta empire at the close of fourth century A.D.

4.3.1 Social Organisation

In the Gupta empire, the main mode of production was still agriculture. The Gupta kings continued the land acquisition started by the Mauryans. Samudragupta conquered a number of forest kingdoms in the valleys of the Ganges, Narmada and Mahanadi. The pattern of land settlement in this period was, however, very different from that of the Mauryans. State control and ownership of the cleared land was greatly reduced and land passed into private ownership. New laws were enacted to allow individuals to administer land and collect taxes, irrespective of whether they tilled the land or not. Most of the Gupta kings, irrespective of their individual religious faith, were secular as far as the state was concerned. Buddhism, Jainism and traditional Hindu institutions were all supported by the state through grants and patronage.

Lineage which had determined one's position in society, gave way, to a certain extent, to one's property status. Thus, Brahmins lost their pre-eminence. Importance of agricultural and craft production meant some improvement in the condition of the Sudras. In general, what one did in society became important. Even Brahmins were obliged to take up occupations other than performance of religious rites.

This relaxation of rigid state control of the previous era had a liberating influence initially, as it encouraged individual initiative. It heralded a certain decline in the hold of the Brahmins and that of the rigid *'varna'* system over agricultural society.

So far, we have described the nature of social organisation in the Gupta period. We find that the social structure in that period was very different from the days of the Mauryan empire. We shall now tell you about the tremendous improvement in techniques and crafts that took place in the Gupta empire.

4.3.2 Improvement of Techniques and Crafts

In this period, there was a spurt in agriculture, as new techniques and seeds were introduced. More importantly, the crafts greatly improved in terms of quality as well as variety. We shall discuss the improvements in agriculture and crafts in this section. We shall also tell you how the growth in trade helped this process.

Agriculture

Pepper and spices were grown for export as well as domestic consumption. A wide variety of crops like rice, wheat, barley, sesame, pulses, beans and lentils, vegetables such as cucumbers, onions, garlic, pumpkin, and betel were grown. New fruits like pears and peaches were introduced for the first time. All this did not take place at random or as a matter of chance. There were proper manuals which gave information on the type and quality of soil required for each plant, various plant diseases, the distances between plants as well as sowing techniques (e.g., working of the soil before sowing). These manuals also described techniques for processing grain, vegetables and fruits. As a wide variety of soil types had to be cultivated, new varieties of agricultural implements also appeared. Weights and designs of ploughshares for different types of soil were fixed and the use of iron for making agricultural implements became widespread.

Crafts

Rapid strides were made during this era in metallurgical and weaving crafts. Rust-proof iron and copper alloys were found and worked into intricate articles for civilian as well as military purposes (Fig. 4.10). The quality of the articles was so good that they were widely exported, even as far as Africa. In the design of these articles, there was, to an extent, Greco-Roman and Central Asian influence. However, on the whole, they had a local character.

Fig. 4.10: Iron Pillar at Mehrauli, Delhi.

In weaving, techniques were perfected for the making of cotton and silk materials. Manufacture of dyes and their widespread use in colouring textiles came into practice. Indian textile materials, especially from Varanasi and Bengal became famous for their light weight and fine texture. The textiles became popular in the West and became an important commodity for export and trade.

Guilds or *'shrenis'* of artisans in this new situation of reduced state intervention, became powerful and important. They enjoyed a great deal of independence and often drew up contracts among individuals, and even entered into agreements with state authorities. The *'shrenis'* borrowed capital from individuals and paid them back with interest. This gave a tremendous impetus to improve the crafts.

We also find that the improvements in crafts were greatly helped by growing trade.

Trade

The importance of direct producers became greater as internal and external trade reached unprecedented volume and proportions.

Opening up of previously inaccessible and uninhabited regions, organisation of better transport, communication and trade routes helped the growth of trade. The existence of a huge market, spread over a vast empire, gave rise to extensive circulation of money through a flourishing trade. For merchants, just as for artisans, there existed associations which were also known as *shrenis*. The main trade routes were based around the rivers Ganges and Indus. The state still supervised the influx and sale of commodities. Internal trade was augmented by rapid development of foreign trade, actively encouraged through the foreign diplomatic contacts established by the Kushanas, the Satavahanas and the Guptas. Improvement in navigation by the Indians, especially using the knowledge of monsoons, and

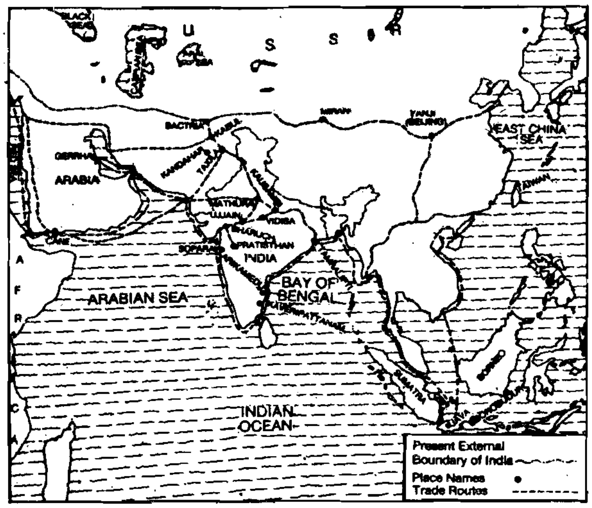


Fig. 4.11: Ancient trade routes.

a new design of seaworthy ships played an important role in this. The Indians traded with Arabs, the Mediterranean countries, especially Rome, Africa, south-east Asian countries such as Java, Sumatra and Sri Lanka. The existence of these associations too, helped the growth of trade (Fig. 4.11).

The above description gives the picture of an Indian society, where commodity production and exchange were in full swing due to an expansion of internal market as well as foreign trade. These activities demanded new techniques of production, new mathematics and numbers to facilitate administration, and new methods of construction, communication and navigation. What is important is that this social demand for new technologies took place in an atmosphere where rigid state control of a previous era had been relaxed in favour of individual initiative. The old ruling elite was, to an extent, giving way. And there was a certain amount of social mobility that possibly encouraged contacts between the literate and illiterate strata of the society. It was a society where the old caste system still prevailed, though somewhat weakened, and where a new caste system, which was not yet oppressive, came into existence, on the basis of division of labour.

It is in this situation that great developments took place in India, in the fields of mathematics and astronomy. We will describe these developments in the next section. But, before reading further, you may like to answer the following SAQ.

SAQ 3

a) List at least three features of the social organisation in the Gupta Empire, that led to a great improvement in science and technology.

....

....

....

....

....

b) Which four of the following innovations in techniques and crafts belong to the Gupta period? Put a tick mark in the boxes given alongside.

i) Building with cement and concrete. ☐

ii) Using new techniques and implements for sowing, growing and processing a wide variety of crops, fruits, vegetables and spices. ☐

iii) Making rust-proof iron and copper alloys. ☐

iv) The use of wind-mills and water-mills. ☐

v) Making textiles of light weight and fine texture, dyeing cloth. ☐

vi) Using bronze ploughshares. ☐

vii) Improvement in navigation resulting from better ships and a knowledge of monsoons. ☐

4.3.3 Developments in Mathematics

We have seen that the tradition of mathematics in India goes back to antiquity. We have already mentioned Sulva geometry in Units 2 and 3. The lineage continues through the Jaina mathematicians who made great contributions over a long period between 500 B.C. and 500 A.D. It is possible that with the development of contact with the Greeks, Indian mathematics came to influence and was also influenced by the Greeks. Further, the Jaina tradition which spread from north to south India in the Gupta period also came into contact with the mathematical schools of Mysore and Ujjain. Whatever be the exact mode of development, what emerged in the Gupta period is a powerful school of arithmetic, algebra and numerals. The formulations became the basis for astronomical calculations to the extent that the great astronomers of the period such as Brahmagupta, Varahamihira and Aryabhatta were known as mathematicians as well as astronomers. The tradition, however, did not end in the Gupta period but continued well into the days of Bhaskara (twelfth century A.D.). It also travelled west and greatly influenced Arab mathematics. Let us see what developments had taken place in mathematics.

Mathematics of the Jainas

The Jainas attached great importance to mathematical proficiency in their religious teachings. Works, such as *Sthananga-sutra* (1st century B.C.), *Suryaprajnapti, Bhadrabahavi Samhita* (300 B.C.), *Ksetrasamasa* by Umasvati (150 A.D.) and others, deal at great length with mensuration, surds, fractions, permutations and combinations, geometry, law of indices, classification of numbers etc. These subjects and the various technical terms used by the Jainas later passed on into the mathematical works of scholars, irrespective of their religious beliefs. We shall now describe some of the important features of the Jaina mathematics in brief.

In mensuration, they worked out the relations between the diameter, circumference, arc and chord of a circle (Fig. 4.12). They also worked out solutions to find approximate value of a surd. We find that the Jainas used large and complicated arithmetical factors. They frequently resorted to approximation in dealing with mixed numbers. Whenever the fractional part was greater than $\frac{1}{2}$, it was replaced by unity, when less than $\frac{1}{2}$, it was neglected. Thus, 315089 was used in place of 315089 $\frac{218}{630}$ and 318315 in place of 31814 $\frac{550}{636}$.

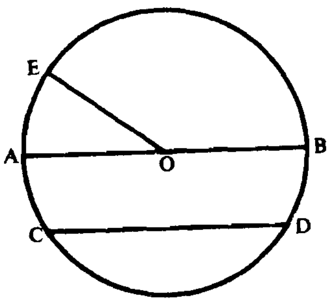


Fig. 4.12: A circle, with its centre at O diameter AB, chord CD and arc AE.

In *Bhagavati-sutra* (1st century B.C.), Jainas speculated about the possible numbers of combinations out of 'n' fundamental categories, taken one at a time (*ekaka-samyoga*), two at a time (*dvika-samyoga*), three at a time (*trika-samyoga*), or more at a time. In all cases, they succeeded in finding the permutation and combination formulas known to us today.

The Jainas could find formulas like

$$ {}^{n}c_1 = n, $$

$$ {}^{n}c_2 = \frac{n(n-1)}{1\times 2}, $$

$$ {}^{n}c_3 = \frac{n(n-1)\,(n-2)}{1\times 2\times 3}, $$

$$ {}^{n}p_1 = n, $$

$$ {}^{n}p_2 = n(n-1) $$

$$ {}^{n}p_3 = n(n-1)\,(n-2) $$

An implicit basic formulation used in all Jaina work on numbers is the modern law of indices:

$a^m \times a^n = a^{(m+n)}$, and $(a^m)^n = a^{mn}$

where m, n may be integral or fractional.

Algebra in India

As a distinct branch of mathematics, algebra appeared from about the time of Brahmagupta (about 598 A.D.). Indian algebraists, possibly for the first time in history, used abbreviations of names of colours or gems, as symbols of unknown quantities, and operations, like powers, roots etc. Some of these notations are shown in the Table 4.1 They distinguished negative quantities by a dot. If a number had no dot, it was supposed to be positive.

The Jaina notation for a negative number, say −2, was • 2.

Table 4.1: Some present day mathematical notations with the corresponding ancient symbols.

Present Day Notation	Notation in Ancient Times
Variables	**Variables**
x, y, z etc.	ma (manikya)
	ni (indranila)
	mu (mukta) etc.
Operations	**Operations**
$+$	yu (yuta)
$-$	+ (from the Brahmi symbol for K in ksaya)
$\times$	gu (guna)
$\div$	bha (bhaga)
$(\ )^2$	va (varga)
$(\ )^3$	gha (ghana)
$(\ )^4$	va-va
$\sqrt{\ }$	mu (mula)

They had classified algebraic equations into three groups:

i) equations in one unknown,

ii) equations in several unknowns,

iii) equations with products of unknowns.

Solutions of linear and quadratic equations were known to them. They also knew how to find solutions for indeterminate equations of the first and second degree with more than one unknown, such as

$by = ax + c$

and $ax^2 + c = y^2$.

Solutions of higher degree equations were also attempted by them.

Numerals

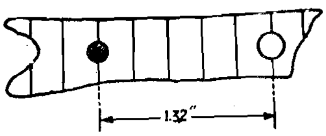


Fig. 4.13: Sketch of an Indus scale.

Apart from algebra, possibly the greatest contribution of ancient Indian civilisation was the invention of numerals. The necessity for numerals and numerical notation by words and letters had arisen when human beings started dealing with very large and very small numbers, such as in astronomy and in precision measurements of precious metals. We have already pointed out that the expansion of trade and navigation in this age promoted these areas of science. Human beings could no longer express their trading exchanges, number and distance of stars or even number of days denoting the periodicity of a star by vertical strokes one after the other as was the custom since the times of Harappan civilisation (Fig. 4.13).

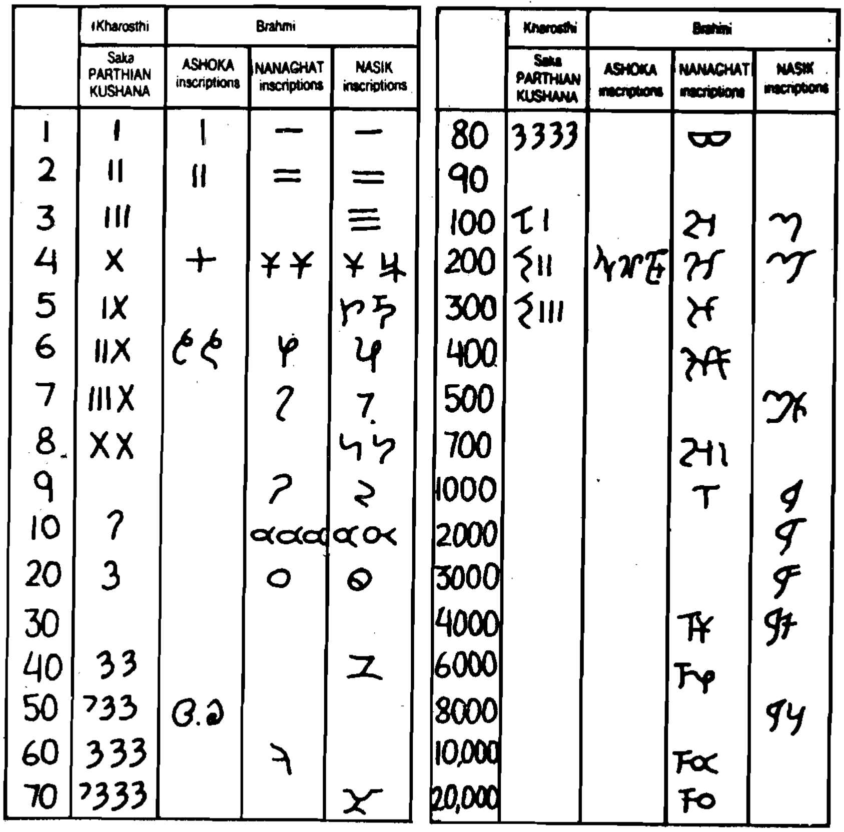
Some of the numeral notations used in this period, namely the Kharosthi and Brahmi systems, are shown in Table 4.2. The Kharosthi numerals are found in the Asokan, Saka, Parthian and Kushana inscriptions of the period from the fourth century B.C. to the second century A.D. You will notice numbers only upto 300 in this system, starting with 1 upto 10, then multiples of 10 upto 100, then 200 and 300. Intermediate numbers were written on the additive principle. Some examples are given below:

Present-day numbers:	22	74	122	274
Can be written as:	2 + 20	4 + 70	2 + 20 + 100	4 + 70 + 200

Kharosthi symbols:

You could try writing some other numbers using the Kharosthi numerals ! Isn't it fun? The Brahmi system which goes up to 20,000 is more sophisticated and uses more abstract symbols. But both these systems are very cumbersome when compared with the decimal system that we use today.

Table 4.2: Numerals in the Kharosthi and Brahmi systems.



The decimal or zero system was first found in a Gurjara grant-plate inscription of 595 A.D. and, later, in other stone inscriptions from Gwalior, Mahipala, Bauka etc. It seems to have been used by contemporary and later astronomers who continuously improved it. Arabs adopted this system and greatly improved upon the earlier numerals, so much so that today these numerals are called Arab numerals or numbers.

In India, the numerals were expressed by names of things, beings or ideas. The word-names were selected by considering their association with numbers. For example,

i) Cipher, zero or 0 was expressed by *kha, akasa, ambara, sunya,*

ii) 1 by earth synonyms, like *bhu, dhara, prithvi, adi* etc. or by moon synonyms, like *indu, chandra* etc.,

iii) 2 by *yama, asvin* (twins), *paksa* (two wings of bird) or *kara* (two hands) etc.,

iv) 3 by (tri) *guna,* (tri) *jagata, agni, rama* etc.,

v) 4 by *veda, samudra,* etc.

vi) 5 by *bhutas* (elements), *indriya* (sense organs) or *sara.*

The way of writing large numbers was quite complicated. Words were compounded to express large numbers. The word numerals were read in the verse from left to right. However, the numbers they represented were arranged from right to left. For example, the number 14400 was written as

kha-kha-veda-samudra-sitarasmayah

When represented numerically from right to left, it would read 1 4 4 0 0. Similarly, we have shown other examples in Table 4.3. You will find some word-names of the numbers 6 to 9 in this table.

Table 4.3

Words	Numbers
1 *nava-vasu-guna-rasa-rasah*	6 6 3 8 9
2 *svara-yama-yama-dvi*	2 2 2 7
3 *sunya-dvi-pancha-yama*	2 5 2 0
4 *vasu-veda-yama-kha-dhara*	———
5	5 3 7 9

SAQ 4

Fill in the blank spaces in Table 4.3, writing the number or the word as required.

You may like to write a few more numbers in the language of our forefathers!

Thus, we see that, for the first time, a system was being worked out so that numbers could be expressed as words, in writing or in speech.

In this section, we have tried to give you a brief glimpse into the major advances in mathematics that took place about 1500 to 2000 years ago. Let us now read about the developments in astronomy which were also very impressive.

4.3.4 Developments in Astronomy

While there is no doubt that great advances were made in astronomy during the Gupta period, it is difficult to assign exact chronological order to discoveries and theories, or to assess the influence of earlier works of Indian and Greek origin in this field. The source of most information is commentaries by later astronomers, who very often attributed their own work to earlier sages in order to gain acceptability by the contemporary Brahmin law makers. An assessment of the exact stage of knowledge is further complicated by the fact that scientists, again to gain social acceptability, mixed all kinds of irrelevant and imaginary religious characters (such as Rahu and Ketu) and causes with their otherwise impeccable scientific theories.

We have seen in Unit 3 that the origin of Indian astronomy can be traced to the Vedic times. These have been described in texts called Siddhantas. The Indian astronomy of those times recorded accurate observations of the sun, moon and planets. It could not, however, build a rational and convincing theory of how the planetary system worked.

Aryabhatta, born in 476 A.D., was the greatest astronomer of the Gupta period. It was his firm belief that the earth was rotating, and the heavens resting. He also gave a scientific explanation for the occurrence of eclipses as opposed to the prevailing ideas that Rahu and Ketu caused eclipses.

Another great achievement to Aryabhatta's credit was the construction of trigonometric tables. He computed trigonometric tables geometrically and used the values of 'sine' and 'cosine' in his astronomical calculations. Besides these, he developed formulas for the sum of arithmetic and geometric series, and worked out the sum of series such as $\sum n^2$ and $\sum n^3$.

Aryabhatta was followed by Varahamihira (born 505 A.D.), who recorded the works of Aryabhatta and older astronomical findings in his classic work *Brihatasamhita*. The problem with Varahamihira was that he attempted to raise astrology to the level of scientific astronomy. This was possibly due to the pressures exerted on him by the Brahmin law makers. Varahamihira, a Brahmin himself, was employed in the king's court. For him to be able to continue with his work on astronomy, he had to gain the favour of priests and the king. He was, possibly, in an awkward position and had to reconcile the demands of science and the decrees of the rishis which were deemed to be infallible. Thus, he included astrology as one of the three main components of his astronomical treatise. While he worked out the horoscopes of the kings and princes to earn a living, his scientific training asserted itself whenever possible, without sacrificing his social standing.

For example, after describing the nature of the two eclipses, according to the prevailing state of observation and on fairly scientific grounds, he complained to those who did not know this. He said, "However, common people are always very loud in proclaiming the Head (Rahu) to be the cause of an eclipse, and they say, 'if the Head were not to appear and were not to bring about an eclipse, the Brahmins would not at that moment be taking an obligatory washing'."

One may sympathise with Varahamihira for the frustrations and tensions he had to bear. But the practice that he introduced, of bringing on par science and non-science to explain natural phenomenon, most probably blocked any significant growth of Indian astronomy after Aryabhatta. For, in another hundred years time, even the astronomers did not object to the Rahu-Ketu explanation of eclipses. Brahmagupta, (born 598 A.D.), an otherwise excellent scientist, proclaimed in *Brahmasphuta-siddhanta*, "Some people think that the eclipse is not caused by the Head (Rahu). This, however, is a foolish idea, for it is he in fact who eclipses. ... The Veda which is the word of God from the mouth of Brahma, says that the Head eclipses". He made this statement, of course, with full knowledge that he was going against the scientific writings of Aryabhatta, Varahamihira and Srisena. He maintained that if Rahu etc. were considered illusory, as was done by Aryabhatta and Varahamihira, "then one will not be blessed with heavenly bliss. . . . he then stands outside of the generally acknowledged dogma and that is not allowed".

We find that the compromises between science and non-science, which the Indian astronomers after Aryabhatta increasingly practised, took the real scientific challenge out of Indian astronomy. Astronomy gave way more and more to astrology, and what was, indeed, one of the most promising schools of science in the world, became a victim of the pressures of politics and dogma. This is best exemplified when one considers the fate of one of the most brilliant suggestions of Aryabhatta, that the earth rotated while the heavens stood still. Atharvaveda invoked ritual metaphysics to maintain that the earth was motionless. Anything which went against this statement was heretical. Aryabhatta, from that point of view, was a heretic. Modern historical research shows that a whole series of astronomers including Varahamihira, Brahmagupta and Lalla either ignored the above statement of Aryabhatta or deliberately misinterpreted it. They wanted to show to their Brahmin masters that they were good Hindus who firmly believed in the Vedas and the geocentric (earth-centred) universe. Some opinion today even raises the possibility of deliberate tampering of manuscripts to erase any mention of a heliocentric (sun-centred) hypothesis.

SAQ 5

In the table given below, which works of astronomy given in column 2 are attributed to the astronomers mentioned in column1. List the works against each astronomer's name.

1	2
a) Aryabhatta	i) Eclipses are caused by Rahu and Ketu.
	ii) The earth rotates and the heavens are still.
b) Varahamihira	iii) The earth is motionless and the sun, moon and the planets move around it.
c) Brahmagupta	iv) Eclipses are caused by the shadows of earth or moon.

The glorious phase in Indian science did not last forever. Its end was signalled by the decline of the Gupta empire which we will now describe, in brief.

4.3.5 Decline of the Gupta Empire

By the second half of the fifth century A.D., the Gupta Empire got considerably weakened. The Huns attacked from the north and occupied not only Punjab and Rajasthan, but eastern Malwa and a good portion of central India. Inscriptions of Huns have been found in central India. Internally, the Governors appointed by the Gupta kings tended to become independent. By the beginning of the sixth century A.D., they had started issuing land grants in their own right. Especially, the loss of western India deprived the Guptas of the rich revenues from trade and commerce. Maintenance of a large professional army and the practice of land grants, for religious and other purposes, became more and more difficult with depleted economic resources. As the economy began to break down, the demand for crafts and commodities was greatly reduced, leading to many of the skilled workers taking up non-productive professions. The migration of a guild of silk-weavers from Gujarat to Malwa in 473 A.D. is one such instance.

Thus, both internal and external factors, as described above, combined and led to a decline of the Gupta empire. This fragmented empire could hardly provide the social and intellectual milieu for the growth of science. With the decline of Gupta empire, the Indian society entered a long phase of turmoil and conflict. The only exception was the Chola empire in southern India, where the techniques and crafts prospered once again, as in the Gupta period. We will now describe in brief, the development in India upto the time that marks the advent of Islam.

4.4 AGE OF CONFLICT

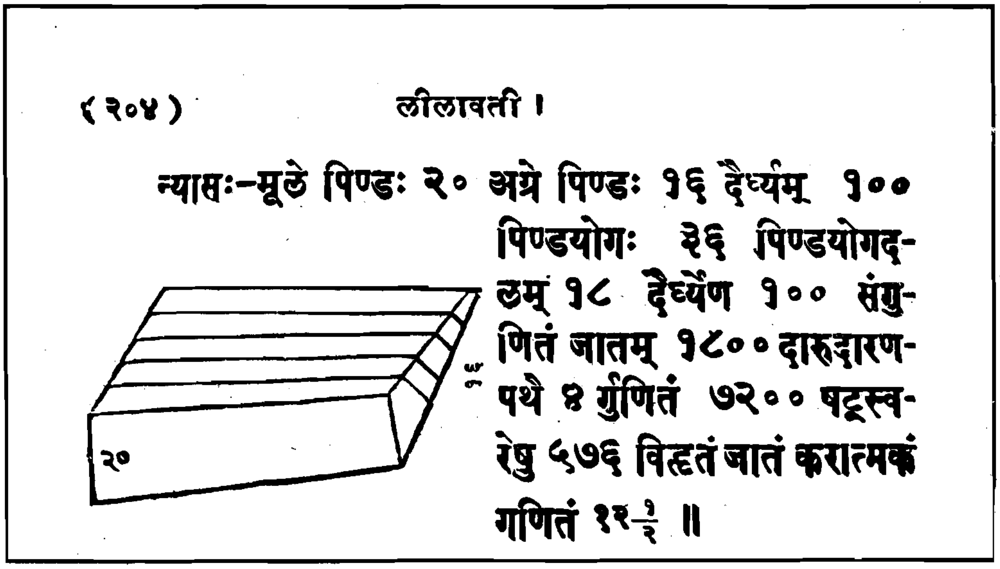
The period between 750 to 1000 A.D. saw a struggle for domination between the Pala empire in north-east, Pratihara empire in the north-west and the Rashtrakutas in the Deccan who also controlled territory in north and south India at various times. By the ninth century, Chola kings had consolidated their power in southern India by defeating the Pallavas, the Chalukyas, the Pandyas and the Rashtrakutas.

The Sassanid dynasty and the Persian empire (the present-day Iran) date from 227-637 A.D.

In northern India, this period was a period of stagnation and decline. The collapse of the Roman and Sassanian empires, with which India had a flourishing and profitable trade, led to a serious setback to trade and commerce. This was accompanied by the rise of small fiefdoms within the empire who were constantly on the look out for asserting their independence. The small fiefdoms encouraged an economy in which villages or groups of villages tended to become largely self-sufficient, thus discouraging trade.

The caste system again became more firmly entrenched, exalting the privileges of the Brahmins and emphasising the social and religious disabilities of the Sudras. A large number of castes, such as potters, weavers, goldsmiths, musicians, barbers, road-makers, and others practising similar crafts were regarded as lowly. The intellectual effort was directed towards justifying and maintaining the rigid caste system. The general decay in society is also reflected in the position of women during that period. They were considered mentally inferior and denied the right to study Vedas. The marriageable age of girls was lowered from sixteen or seventeen years in the Vedic period to six or eight years, thus, destroying the opportunity for their personal development.

However, even in this state of general decay, there were some remarkable individual efforts. Aryabhatta II (about 950 A.D.) made significant contribution to astronomy and mathematics. Bhaskara II (born 1114 A.D.) wrote his famous mathematical-astronomical work *Siddhanta-Shiromani* which is divided into four parts, *Lilavati, Bijaganita, Ganitadhyaya and Goladhyaya* (see Fig. 4.14).


(२०४)　　लीलावती ।

न्यासः—मूले पिण्डः २० अग्रे पिण्डः १६ दैर्घ्यम् १०० पिण्डयोगः ३६ पिण्डयोगदलम् १८ दैर्घ्येण १०० संगुणितं जातम् १८०० दारुदारणपथै ४ गुणितं ७२०० षट्स्वरेषु ५७६ विहृतं जातं करात्मकं गणितं १२$\frac{१}{२}$ ॥

Fig. 4.14: A page from Lilavati, as reconstructed in recent times showing the application of a formula to calculate the total cross-sectional area when a block of wood is cut in four places.

With this, we end the story of a remarkable phase in the development of science in ancient India. If you want to know more details about these advances, you could read some of the books listed at the end of this block.

4.5 SUMMARY

- We have seen, in this unit, that a powerful centralised state had emerged in India by the fourth century B.C. The rising state not only needed land for agriculture but also the methods to improve agricultural produce. They needed mineral resources to make agricultural tools, as well as to make weapons for the huge army that was maintained to consolidate the empire. In this process, they subjugated the tribal people and took over their land. They also needed the help of the tribals for tilling the land and exploiting the resources. For this, they assimilated the tribals and a cultural synthesis took place, leading to a flexibility in social relations.

- The period also saw the emergence of Buddhism and Jainism, with their liberal philosophy and outlook.
- These developments provided a stimulus to the growth of science and technology in the Maurya period. There was significant improvement in various techniques and crafts. However, the Mauryan empire declined following Asoka's reign.
- The period from about the first century B.C. to the second century A.D. was one of the most flourishing periods in the history of crafts and commerce in southern India.
- In the Gupta period, the highly centralised state power gave way to a more flexible and local administration. The artisans and traders had their guilds and were represented in the local administration. The Gupta kings made land grants to the Brahmins on a large scale which resulted in the emergence of priestly landlords. These social changes led to initiative at local level. Thus, they provided an incentive for increasing agricultural output and introducing new crafts and techniques. But, this also resulted in lowering the status of the local tribal peasant.
- Mathematics and astronomy made major advances as revealed in the works of Jaina mathematicians and astronomers like Aryabhatta. The Gupta craftsmen distinguished themselves by their work in iron and bronze. The Iron Pillar (dated around 400 A.D.), at Mehrauli in Delhi, is a testimony of their technological skill.
- With the decline of Gupta empire, the development of science suffered a setback. Hereafter, there were a few advances made solely by individual efforts.

4.6 TERMINAL QUESTIONS

Give short answers in three or four lines.

1) What was the difference between the socio-political organisation of the state during the Maurya and the Gupta periods?

....

....

....

2) Which unscientific practice led to the decline of astronomy in India?

....

....

....

3) What features in Indian society led to the decline of science in the post-Gupta period?

....

....

....

4.7 ANSWERS

Self Assessment Questions

1) (i), (ii), (iii), (iv), (vi).

2) a) Building of corduroy roads.
   b) Introduction of plough agriculture and use of many forms of irrigation.
   c) Technology for husking grain, carding cotton and wool, spinning yarn etc.
   d) Metallurgy and metal working.

3) a) i) State control was greatly relaxed and individual initiative was encouraged.
      ii) In general, instead of one's lineage, property status and what one did in society became important.
      iii) Importance of agricultural and craft production led to an improvement in the condition of manual-workers like peasants and Sudras.
   b) (ii), (iii), (v), (vii).

4) 10248, *nava-svara-guna-bhuta*
5) a) (ii), (iv).
   b) (iii), (iv).
   c) (i), (iii).

Terminal Questions

1) The state was highly centralised in the Maurya period, whereas in the Gupta period the rigid state control was relaxed and individual initiative was encouraged.
2) The unscientific practice of treating astrology at the same level as astronomy.
3) i) The emergence of small fiefdoms which encouraged a self-sufficient village economy and discouraged trade.
   ii) The caste system became rigid and firmly entrenched.
   [Note : You could expand these answers].

GLOSSARY

algebra : branch of mathematics, dealing with properties of, and relationship between quantities by means of general symbols

alloy : mixture of metals

anarchy: absence of government, disorder

anatomy: science of structure of living organisms

archaeological: related to the study of ancient human societies, especially prehistoric, usually by digging the sites

arithmetic: the science of numbers

artefacts: products of human art and craftsmanship

astronomy: science of the planets, stars and other heavenly bodies

axle : the slender bar or rod, on or with which the wheel revolves

barbarian: less civilised person

botany: the scientific study of plants

brewing : making of beer, wine by boiling and fermentation

carding of cotton: removing seeds from cotton

centrifugal force: outward force acting on a body rotating in a circle round a central point

chemistry: science of the nature of matter and the changes it undergoes

classification: arranging in different categories

commodity production: production of goods for trade only

constellation: a definite region of the sky mapped by a group of stars

corduroy roads: roads made of wooden logs, especially in swampy and marshy places

cosmogonic systems: theories about the origin of the universe, earth and the world

cuneiform: writing in strokes, impressed by a wedge-shaped object on clay tablets, seals, stone pillars etc.

diagnosis: identifying patient's disease by the symptoms

dynamics of a society: changes in society and all the forces operating in society

embryology: science of development of unborn or unhatched offspring

emetic : medicine that causes vomiting

empirical: relying on observation and experiment

evolutionary tree: a diagram depicting various stages of evolution

fermentation : a chemical change brought about in substances by living organisms (yeast, bacteria etc.), giving off gases, heat etc.

fiefdom: small feudal states

geocentric: model of the universe in which the earth is at the centre and other heavenly bodies move around it

geometry: mathematical study of properties and relations of lines, surfaces and solids in space

heliocentric: model of the solar system in which the sun is at the centre and the planets move around it

heredity: sum of characteristics inherited from parents

heresy: opinion contrary to the accepted doctrine on any subject

hierarchy: graded organisation

hieroglyphics : writing in which the figure of an object stands for a word

horticulture: cultivation of plants, especially in gardens

hypothesis: assumption or supposition made as a basis for investigation

ideology: ideas characteristic of a class or ideas at the basis of some economic or political systems

innovations: bringing in new changes

lyceum: teaching place

means of production: land, machines and methods used for making various goods of use and consumption

mechanics: science of motion of rigid bodies, causes of motion, properties of materials etc.

medieval: of the Middle Ages (around 5th century A.D. to 15th century A.D.)

metallurgy: art of working metals, especially extracting metals from ores

metaphysics: theoretical philosophy of being and knowing

monarchy: government under one king or one sovereign ruler

morphology: study of form and structure of animals and plants

natural history : study of animal or vegetable life, collection of facts about natural objects

nomadic: wandering from place to place

objective: dealing with facts, independent of feelings or opinions

oil wheel: device for extracting oil from seeds

ores: mixture of minerals found in nature from which metal can be extracted

pastoral life: life spent in rearing herds of animals

perspective: view

physics : the study of properties of matter and energy

physiology: science of the normal functions of living organisms

pitch : hard dark substance obtained from distillation of coal tar or turpentine

primitive: ancient, undeveloped

prognosis: forecast of the probable course of disease

purgative : laxative medicine, serving to purify the digestive system

reagents: substance used to cause reaction

reducing the ores: conversion of ores, especially metal-oxide ores by heating with coal

sexagesimal system : a system based on multiples of the number sixty

slash and burn cultivation: preparing land for cultivation by cutting and burning trees

smelting: extracting metal from ore by melting

stagnation: state of inertia; inactive, dull or slow moving state

technique: skilful means of achieving one's purpose; mechanical skill, application of science

therapeutic: related to treatment or cure of disease

zoology : the scientific study of animals

FURTHER READING

1 *Ancient India,* A Text book for Class XI, R.S. Sharma, NCERT, 1986.

2 *The Story of Civilization,* Vol. I, Arjun Dev, NCERT, 1987.

3 *A Concise History of Science in India,* Ed. by D.M. Bose, S.N. Sen, B.V. Subbarayappa, Indian National Science Academy, 1971.

4 *An Introduction to the Study of Indian History,* D.D. Kosambi, Bombay, 1956.

5 *The Culture and Civilisation of Ancient India in Historical Outline,* D.D. Kosambi, Vikas Publishing House, 1987.

6 *Science and Society in Ancient India,* D.P. Chattopadhyaya, Research India Publications, Calcutta, 1979.

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