HISTORY
OF
SCIENCE AND TECHNOLOGY IN INDIA

By
Dr. Binod Bihari Satpathy

CONTENT

HISTORY OF SCIENCE AND TECHNOLOGY IN INDIA

UNIT-1
Chapter-I

DEVELOPMENT IN DIFFERENT BRANCHES OF SCIENCE IN ANCIENT INDIA
Astronomy, Mathematics, Engineering and Medicine

Structure

1.1.0. Objectives

This chapter will discuss the development of different sciences in ancient India. After studying this lesson the students will be able to:

- *know the origin and development of astronomy in ancient India;*
- *understand the origin and growth of mathematics in ancient India.*
- *assess the growth of engineering in ancient India.*
- *identify the evolution and growth of medicine in Ancient India.*
- *list the contributions of India to the world in the field of Mathematics and other Sciences.*

1.1.1. Introduction

The impression that science started only in Europe was deeply embedded in the minds of educated people all over the world. The alchemists of Arab countries were occasionally mentioned, but there was very little reference to India and China. Thanks to the work of the Indian National Science Academy and other learned bodies, the development of sciences in India during the ancient period has draw attentions of scholars in 20th century. It is becoming clearer from these studies that India has consistently been a scientific country, right from Vedic to modern times with the usual fluctuations that can be expected of any country. In fact, we do not find an example of a civilization, except perhaps that of ancient Greece, which accorded the same exalted place to knowledge and science as did that of India. This chapter will throw lights on the sphere of sciences in which ancient Indian excelled.

1.1.2. Mathematics

Vedic Hindus evinced special interest in two particular branches of mathematics, viz. geometry and astronomy. Sacrifice was their prime religious avocation. Each sacrifice had to be performed on an altar of prescribed size and shape. They were very strict regarding this and thought that even a slight irregularity in the form and size of the altar would nullify the object of the whole ritual and might even lead to an adverse effect. So the greatest care was taken to have the right shape and size of the sacrificial altar. Thus originated problems of geometry and consequently the science of geometry. The study of astronomy began and developed chiefly out of the necessity for fixing the proper time for the sacrifice. This origin of the sciences as an aid to religion is not at all unnatural, for it is generally found that the interest of a people in a particular branch of knowledge, in all dimes and times, has been aroused and guided by specific reasons. In the case of the Vedic Hindu that specific reason was religious. In the course of time, however, those sciences outgrew their original purposes and came to be cultivated for their own sake. The following paragraphs will discuss the history of mathematics in ancient India.

1.1.2.1. Vedic Period

The *Chandogya Upanisad* mentions among other sciences the science of numbers. In the *Mundaka Upanisad* knowledge is classified as superior and inferior. The term *ganita*, meaning the science of calculation, also occurs copiously in Vedic literature. The *Vedanga Jyotisa* gives it the highest place of honour amongst all the sciences which form the Vedanga. At that remote period *ganita* included astronomy, arithmetic, and algebra, but not geometry. Geometry then belonged to a different group of sciences known as *kalpa.* Available sources of Vedic mathematics are very poor. Almost all the works on the subject have perished. There are six small treatises on Vedic geometry belonging to the six schools of the Veda. Thus, for an insight into Vedic mathematics we have now to depend more on secondary sources such as the literary works.

1.1.2.2. Post-Vedic Mathematics

The development of a certain level of mathematical knowledge dictated by the material needs of a society is a common phenomenon of all civilizations. What is noteworthy is that Vedic Hindus went much farther than what was warranted by such needs and developed a natural love for the subject fully in keeping with their propensity for abstract reasoning. That problems of irrational quantities and elementary surds, indeterminate problems and equations, arithmetical and geometrical series, and the like, while engaged in the practical design and construction of sacrificial altars. Although problems of architecture, the intricacies of the science of language such as metre and rhyme, and commercial accounting did stimulate the development of mathematics, its greatest inspiration doubtless came from the consideration of problems of reckoning time by the motions of celestial bodies.

In India, a substantial part of mathematics developed as a sequel to astronomical advancement; and it is no accident that the bulk of post-Vedic mathematics has been found only in association with the *Siddhantas*, a class of astronomical works. The formative period of Siddhantic astronomy may be limited to the first few centuries of the Christian era. These centuries and possibly the few closing ones of the pre-Christian era witnessed the development of mathematics required for adequately expressing, describing, and accounting for astronomical elements and phenomena, as well as for meeting the various needs of an organized society.

Jaina priests showed remarkable interest in the study and development of mathematics. They devoted one of the four branches of *Anuyoga* (religious literature) to the elucidation of *ganitanuyoga* (mathematical principles) and prescribed proficiency in *samkhyana* (science of calculation) and *jyotisa* (astronomy) as an important prerequisite of the Jaina priest. An idea as to the various mathematical topics discussed at this early age and recognized in later Jaina mathematical works such as the *Ganitasara-sangraha* of Mahavira (A.D 850) and *Ganitatilaka* of Sripati (A.D. 999) may be obtained from an extant passage in the *Sthananga-sutra (*1st Cent. B.C.). This passage enumerates*: parikarma* (fundamental operations), *vyavahara* (determination), *rajju* (geometry), *kalasavarna* (fraction), *yavat-tavat* (linear equation), *varga* (quadratic equation), *ghana* (cubic equation), *vargavarga* (biquadratic equation), and *vikalpa* (permutations and combinations). It will be seen that *ganita* then comprised all the three principal branches, viz. arithmetic, algebra, and geometry. Its differentiation into arithmetic *(patiganita* or *vyaktaganita)* and algebra (*bijaganita*, *avyaktaganita*, or *kuttaka)* did not take place until Brahmagupta (A.D 598) sought to emphasize the importance of the two. Treatises exclusively devoted to arithmetic began to appear from about the eighth century A.D. Geometry, which had a somewhat independent career at the time of the composition of the Sulvasutras, formed part of *ganita* and later became largely associated with arithmetic.

1.1.2.3. **Arithmetic**

Decimal Place-value Numeration: It is well known that the development of arithmetic largely centered round the mode of expressing numbers. The early advantage, skill, and excellence attained by Indians in this branch of mathematics were primarily due to their discovering the decimal place-value concept and notation, that is, the system of expressing any number with the help of either groups of words or ten digits including zero having place-value in multiples of ten. An extensive literature exists on the Indian method of expressing numbers, particularly on the decimal place-value notation with zero, and on the question of its transmission to South and West Asia and to Europe leading to its international adoption.

Mathematicians and orientalists are generally agreed that the system with zero originated in India and thence travelled to other parts of the world. In examining the question of India's contribution to the origin and development of the place-value system with zero, the basic facts established from literary and epigraphic sources may be summarized as follows:

At first, from the Vedic times the basis of numeration in India has consistently been ten. Long lists of names for several decimal places are found in the sacred literatures of the Hindus, Jains, and Buddhists. The *Vajasaneyi*, *Taittiriya*, *Maitrdyani*, and *Kathaka Samhitas* give denominations up to 13 places, e.g. *eka* (1), *daja* (10), *sata* (100), *sahasra* (1000),.. .*samudra*, *madhya*, *anta*, and *pardrdha*. Buddhist literature continued the same tradition and introduced a centesimal scale (*Jatottara-ganana*), obtaining the name *talaksana* for the 54th place. The Jains in the *Anuyogadvara-sutra* (*c*. 100 B.C.) called the decimal places *ganana-sthana*, gave a numerical vocabulary analogous to that of the Brahmanic literature, and mentioned fantastically large numbers up to 29 places and beyond. Thus the decimal place-value mode of reckoning was recognized without any ambiguity in the sacred literatures of the pre-Christian period going back to the time of the composition of the Samhitas. This mode of reckoning we find more clearly stated in the mathematical-astronomical texts from Aryabhata onwards in such expressions as *sthanatsthanam dasagunam syat* (from one place to the next it should be ten times) and *daiagunottarah samjnah* (the next one is ten times the previous).

Secondly, the word-numerals and their use in a decimal place-value arrangement represent another unique development in India, designed particularly to compress a large mass of numerical data into versified mathematical texts. The word-names were selected by considering their association with numbers. Thus 0 (zero) was denoted by *kha*, *akaht ambara*, *Sunya*, and their various synonyms, signifying 'emptiness', 'void', 'nothingness', etc.; by earth synonyms, e.g. *ksiti*, *dhara*, *prthivi*, or moon synonyms, e.g. *indu*, *candra*, *abja;*; by *veda*, *samudra*, *arnava*, etc.; and so on. Fabrication of word-numerals may be traced to the *Rg-Veda*, and their use without place-value has been found in the *Satapatha* and *Taittiriya Brahmanas*, the *Vedanga-jyotisa* , and some Sutra texts. Their use in a decimal system appears in the *Agni Purana* and *Panca-siddhantika* (*c*. 6th Cen. A.D) .

Thirdly, Aryabhata I (A.D 476) invented a system of expressing numbers with the help of consonants and vowels, based again on the decimal place value principle. The need for extreme compactness and brevity in using a large number of astronomical constants in verses with due regard to metrical considerations led to this interesting method, explained in the *paribhasa* stanza of his *Daiagitika-sutra*. At about the same time a similar but somewhat improved system of alphabetical notations called *katapayadi* was developed and used in mathematical-astronomical texts. The system, employing place-value, was known to Aryabhata I; it was used by Bhaskara I (A.D 574) and Aryabhata II (A.D.950), and applied in the astronomical *Jaimini-sutras* of unknown date.

Fourthly. there are several references to zero in literary works before its appearance in inscriptions and texts in association with numerals. In Pingala's *(c.* 200 B.C.) *Chandah-sutra* zero is mentioned in the rules for calculating the number of long and short syllables in a metre of *n* syllables. The Bakhshali Manuscript (A.D 200) uses zero in calculation and represents it by a dot as does the Kashmir recession of the *Atharva-Veda*. The Sanskrit name for this zero-dot is *Sunya-bindu* as is clearly stated in Subandhu's *Vasavadatta (*A.D 600). In the Srivijaya inscriptions of Palembang in Sumatra, a dot is used in writing the zero of the number 605. The early Arab writers on the Hindu numeral system, such as Ibn Wahshiya *(*A.D. 855) and Al-Nadim (A.D 987), used dots to represent zero. The Hindu term for zero-*Sunya*, meaning 'void'-passed over into Arabic as *as-sifr* or *sifr*.

Fifthly, the Kharosthi numerals are found to occur in the Asokan, Saka, Parthian, and Kusana inscriptions dating from the fourth century B.C to the second century A.D. Strokes and crosses were used for the first eight digits. The multiplicative principle was used in developing symbols for multiples of 100 up to 900. No sign for 1000 is known. Where additive principle was applied, numeral symbols were used on the left-hand side, and in the case of the multiplicative principle, on the right hand side. For writing conjugate numbers the left to right method, similar to the word-numeral arrangement, was followed. The Brahmi numerals are more sophisticated in their forms. They have separate signs for numbers 1, 4 to 9, 10 and its multiples up to 90, and for 100, 1,000, etc. Multiples of 100 and 1,000 up to 9,000 are derived on the multiplicative principle, as in the case of the Kharosthi for multiples of 100. A few examples are given.

More than thirty inscriptions giving decimal place-value numeral notations are known. A circular symbol for zero appears in the Gwalior inscription of the reign of Bhojadeva in which the verses are numbered from 1 to 26 in decimal figures. In another Gwalior inscription the date Vikrama Samvat 933 and the numbers 270, 187, and 50 are given in the decimal place-value system. Those who are reluctant to rely on any evidence other than the palaeographic in such matters have emphasized the importance of the Gwalior inscriptions and cited these as unmistakable proof of the existence in India of a decimal place-value notation with zero.

Sixthly, curiously enough, decimal place-value numerals with a point symbol as well as a circular symbol for zero appear in three specimens of seventh century inscriptions of Srivijaya in the Hindu colonies of South-East Asia- two at Palembang in Sumatra and one in Banka. These give the Saka dates 605, 606, and 608 in figures. Another old Srivijaya inscription found in Sambor gives the Saka date 605 in the same way. In Java two fragments of inscriptions have been found in Dinaya which express the same date in word numerals as well as in figures in the decimal place-value arrangement. Thus the Saka date 682 is written as *nayana-vasu-rasa* and is also repeated in figures. It is natural to conclude that the numerals with zero had originated in India and travelled to South-East Asia with the Hindu colonizers.

***Extraction of Square and Cubic Roots*:** the above discussion shows that, the development of the decimal place-value notation also meant the evolution of a new kind of arithmetic. Let us take the case of the extraction of square and cube roots of large numbers. In India the method first appeared in the *Aryabhatiya* (A.D. 499). This was followed by Brahmagupta (A.D. 598) who, however, did not give any rule for square root extraction. Subsequently, Mahavira *(*A.D 850), Sridhara *(*A.D 991), Aryabhata II (A.D 950), Bhaskara II *(*A.D 1150), and Kamalakara (A.D 1658) gave fundamentally the same rules. The method of extraction of the cube root of any integral number has been traced to the *Ganitapada* of the *Aryabhatiya*. The same method is given by Brahmagupta in his *Brahmasphuta-siddhdnta*. Subsequent Indian authors have given the same method in a less cryptic style.

1.1.2.4. Algebra

The beginnings of algebra, or more correctly, the geometrical methods of solving algebraic problems, have been traced to the various *Sulvasutras* of Apastamba, Baudhayana, Katyayana, Manava, and a few others. These problems involving solutions of linear, simultaneous, and even indeterminate equations arose in connection with the construction of different types of sacrificial altars and arrangements for laying bricks for them. The differentiation of algebra as a distinct branch of mathematics took place from about the time of Brahmagupta, following the development of the techniques of indeterminate analysis *(kuttaka).* In fact, Brahmagupta used the terms *kuttaka* and *kuttakaganita* to signify algebra. The term *bijaganita*, meaning 'the science of calculation with elements or unknown quantities' *(bija)*, was suggested by Prthudakasvamin (A.D 860) and used with definition by Bhaskara II. Brahmagupta gave the following classifications: (1) *eka-varna-samikarana*-equations in one unknown, comprising linear and quadratic equations; (2) *aneka-varna-samikarana*-equations in many unknowns; and (3) *bhavita*-equations containing products of unknowns.

***Quadratic Equations*:** The Sulvasutras contain problems involving quadratic equations. The Bakhshali Manuscript gives the solution of a problem in a form which reduces to None of them gives any rule for solving such equations. Both Aryabhata I and Brahmagupta clearly indicate their knowledge of quadratic equations and the solutions thereof.

***Indeterminate Equations*:** The branch of algebra dealing with indeterminate equations of the first degree has interested Indian mathematicians and astronomers presumably from the time of the Sulvasutras. These manuals contain rules and directions which point to the solution of simultaneous indeterminate equations of the first degree. Thus the *Baudhayana Sulvasutra* prescribes rules for the construction of a *garhapatya vedi* (sacrificial fire altar) which lead to indeterminate equations. Detailed rules of solution are given in the works of Aryabhata I, Brahmagupta, Bhaskara I, Mahavlra, Aryabhata II, Bhaskara II, and later authors and commentators. Indeterminate analysis had an immediate application in astronomy in the determination of the cycle *(yuga)* of planets from the elapsed cycles of several other given planets. Further refinements, clarifications, and extensions were due to subsequent Indian mathematicians such as Sripati, Bhaskara II, and Narayana, and several commentators who made no mean contribution to this branch of algebra. Hankel, the well-known historian of mathematics, praise the achievement of the Hindu mathematicians in this field.

Permutations and Combinations*, *Pascal Triangle*, *and Anticipation of Binomial Theorem: In the early Jaina canonical literature, permutation was termed *vikalpa-ganita* and combination, *bhanga***.** Later on the term *chandaiciti* was adopted to signify permutations and combinations. The rules had wide applications which Bhaskara II enumerated as follows: 'It serves in prosody, for those versed therein, to find the variations of metre; in the arts (as in architecture) to compute the changes upon apertures (of a building); and (in music) the scheme of musical permutations; in medicine, the combinations of different savours. For fear of prolixity, this is not (fully) set forth.' The *Susruta-samhita* correctly gives the sum of combinations of six tastes taken one at a time, two at a time, etc. up to all at a time. The Jaina *Bhagavati-sutra* calculates the number of combinations of *n* fundamental categories taken one at a time, two at a time, and so on. Varahamihira has stated that 'an immense number of perfumes can be made from sixteen substances taken in one, two, three, or four proportions', and has correctly given the number of perfumes resulting from sixteen ingredients mixed in all proportions.

Varahamihira in his astrological work, the *Brhatjataka*, applied the same principle in connection with planetary conjunctions. An interesting rule for finding the number of combinations of *n* syllables taking 1, 2, 3, etc. up to a at a time has been given in Pingala's *Chandah-sutra* and is known as *meru-prastara.*

1.1.2.5. Geometry

Like other branches of mathematics, geometry in India in the post-Vedic period was developed in the course of dealing with practical problems. Although there are quite a few examples of important results having been obtained, the subject never grew into an abstract and generalized science in the manner it did at the hands of the contemporary Greeks. Problems receiving geometrical treatment were discussed under such topics as *ksetra* (plane figures), *khata* (excavations or cubic figures), *citi* (piles of bricks), *krakaca* (saw problems or cubic figures), and *chaya* (shadows dealing with problems of similarities and proportions). This mode of treatment continued up to the time of Bhaskara II or even later. But it was not until the beginning of the eighteenth century that Euclid's *Elements* was translated into Sanskrit by Jagannatha (A.D 1652) under the title of the *Rekhaganita.* The solution of right-angled triangles, whose sides *a*, *b*, *c* are connected by the relation *a2+b2=c*a, constituted a favourite preoccupation of the ancient Indians. Aryabhata I made a general statement of the theorem. Brahmagupta gave general solutions of such triangles, whose sides can be given in rational numbers.

1.1.2.6. Trigonometry

Trigonometry was developed as an integral part of astronomy. Without its evolution many of the astronomical calculations would not have been possible. Three functions, namely, *jyat kojya* (also *kotijya*), and *utkramajya*, were used and defined in ancient times. Fairly accurate sine tables were worked out and given in most astronomical texts to facilitate ready calculations of astronomical elements. The usual practice was to give the values at intervals of 3°45', although other intervals also were sometimes chosen. Intermediate values were calculated by extrapolation. Brahmagupta, Bhaskara I, and others gave formulas for the direct calculation of the sine of any angle without consulting any table. Thus in trigonometry there is evidence of an unbroken tradition of excellence and originality in India extending over several centuries.

1.1.2.7. Calculus

Rudimentary ideas of integration and differentiation are found in the works of Brahmagupta and Bhaskara II. Bhaskara II, in particular, determined the area and volume of a sphere by a method of summation analogous to integration. In the first method, the surface is divided into elementary annuli by drawing a series of parallel circles about any point on the surface. The number of such circles, according to Bhaskara II, can be as many as desired. The area of the sphere is given by the sum of areas of the annuli. To find the volume of the sphere, it is divided into a large number of pyramids with their bases lying on the surface of the sphere and their apices coinciding with the centre. The sum of the volumes of these pyramids gives the volume of the sphere.

In the definition of *tatkaliki gati* (instantaneous motion) by Bhaskara II and in his method of calculating its value, an elementary conception of differentiation is clearly indicated. The problem is presented in connection with the question of finding the instantaneous velocity of a planet. Earlier, he had given methods of determining the mean and true longitudes of any planet for any instant of time.

In conclusion, it may be stated that mathematics is a specialized discipline the knowledge of which must necessarily remain confined to only a few persons having an exceptional interest in the subject and its application. In India also during the ancient time the study of mathematics was the preoccupation of a few astronomers-cum-astrologers scattered all over the country. Nevertheless, the development of mathematics to the extent we have seen in the foregoing review must be attributed to something special in the intellectual efforts of the Indians of this period.

1.1.3. Astronomy

There is considerable material on astronomy in the Vedic Samhitas. But everything is shrouded in such mystic expressions and allegorical legends that it has now become extremely difficult to discern their proper significance. Much progress seems, however, to have been made in the Brahmana period when astronomy came to be regarded as a separate science called *naksatra-vidya* (the science of stars). An astronomer was called a *naksatra-daria* (star-observer) or *ganaka* (calculator).

1.1.3.1. Astronomy during Vedic Period

Idea on Universe: According to the *Rg-Veda*, the universe comprises *prthivi* (earth), *antariksa* (sky, literally meaning 'the region below the stars'), and *div* or *dyaus* (heaven). The distance of the heaven from the earth has been stated differently in various works. The *Rg-Veda* gives it as ten times the extent of the earth, the *Atharva-Veda* as a thousand days' journey for the sun-bird, the *Aitareya Brahmana* as a thousand days' journey for a horse, and the *Pancavimsa Brahmana* as the distance equivalent to a thousand cows, one standing on the other, and again as a thousand leagues, besides the two preceding estimates. All these are evidently figurative expressions indicating that the extent of the universe is infinite. There is speculation in the *Rg-Veda* about the extent of the earth. It appears from passages therein that the earth was considered to be spherical in shape and suspended freely in the air.

The *Satapatha Brahmana* describes it expressly as *parimandala* (globe or sphere). There is evidence in the *Rg-Veda* of the knowledge of the axial rotation and annual revolution of the earth. It was known that these motions are caused by the sun. According to the *Rg-Veda*, there is only one sun, which is the maker of the day and night, twilight, month, and year. It is the cause of the seasons. It has seven rays, which are clearly the seven colours of the sun's rays. The sun is the cause of winds; says the *Aitareya Brahmana*. It states further: 'The sun never sets or rises. When people think the sun is setting, it is not so; for it only changes about after reaching the end of the day, making night below and day to what is on the other side. Then when people think he rises in the morning, lie only shifts himself about after reaching the end of the night, and makes day below and night to what is on the other side. In fact he never does set at all.' This theory occurs probably in the *Rg-Veda* also. The sun holds the earth and other heavenly bodies in their respective places by its mysterious power. In the R*g-Veda,* Varuna is stated to have constructed a broad path for the sun called the path of the *rta*. This evidently refers to the zodiacal belt. The *Rg-Veda* mentions the inclinations of the ecliptic with the equator and the axis of the earth. The apparent annual course of the sun is divided into two halves, the *uttarayana* when the sun goes northwards and the *daksinayana* when it goes southwards. According to the *Satapatha Brahmana* the *uttarayana* begins from the vernal equinox. But it is clear from the *Kausitaki Brahmana* that those periods begin respectively from the winter and summer solstices. The ecliptic is divided into twelve parts or signs of the zodiac corresponding to the twelve months of the year, the sun moving through the consecutive signs during the successive months. The sun is called by different names at the various parts of the zodiac, and thus has originated the doctrine of twelve *adityas* or suns.

The *Rg-Veda* says that the moon shines by the borrowed light of the sun. The phases of the moon and their relation to the sun were fully understood. Five planets seem to have been known. The planets Sukra or Vena (Venus) and (Mangala) Mars are mentioned by name. The *Taittiriya Samhita* and other works expressly mention twenty-seven *naksatras*. The Vedic Hindus observed mostly those stars which lie near about the ecliptic and consequently identified very few stars lying outside that belt. The relation between the moon and *naksatras* was conceived as being a marriage union. The *Taittiriya Samhita* and *Kathaka Samhita* state that the moon is wedded to the *naksatras*. The ecliptic was divided into twenty-seven or twenty-eight parts corresponding to the *naksatras*, each of which the moon traverses daily during its monthly course.

Methods of observation: It appears from a passage in the *Taittiriya Brahmana* that Vedic astronomers ascertained the motion of the sun by observing with the naked eye the nearest visible stars rising and setting with the sun from day to day. This passage is considered very important 'as it describes the method of making celestial observations in old times. Observations of several solar eclipses are mentioned in the *Rg-Veda*, a passage of which states that Atri observed a total eclipse of the sun caused by its being covered by Svarbhanu, the darkening demon. Atri could calculate the occurrence, duration, beginning, and end of the eclipse. His descendants also were particularly conversant with the calculation of eclipses. In the *Atharva-Veda* the eclipse of the sun is stated to be caused by Rahu the demon. At the time of the *Rg- Veda* the cause of the solar eclipse was understood as the occultation of the sun by the moon. There is also mention of lunar eclipses.

Calculation of Season: In the Vedic Samhitas the seasons in a year are generally stated to be five in number, namely, Vasanta (spring), Grisma (summer), Varsa (rains), Sarat (autumn), and Hemanta-Sisira (winter). Sometimes Hemanta and Sisira are counted separately, so that the number of seasons in a year becomes six. Occasional mention of a seventh season occurs, most probably the intercalary month. It is called 'single born', while the others, each comprising two months, are termed 'twins'. Vedic Hindus counted the beginning of a season on the sun's entering a particular asterism. After a long interval of time it was observed that the same season began with the sun entering a different asterism. Thus they discovered the falling back of the seasons with the position of the sun among the asterisms. Vasanta used to be considered the first of the seasons as well as the beginning of the year. The *Taittiriya Samhita* and *Aitareya Brahmana* speak of Aditi, the presiding deity of the Punarvasu *naksatra*, receiving the boon that all sacrifices would begin and end with her. This clearly refers to the position of the vernal equinox in the asterism Punarvasu. There is also evidence to show that the vernal equinox was once in the asterism Mrgasira from whence, in course of time, it receded to Karttika. Thus there is clear evidence in the Samhitas and Brahmanas of the knowledge of the precession of the equinox.

Equation of time: Some scholars maintain that Vedic Hindus also knew of the equation of time. The Vedas prescribed various *yajnas* or sacrifices to be performed in different seasons of the year. The duration of these sacrifices used to vary; some were seasonal, some four-monthly, some year-long, and others even longer. It was necessary to calculate the time to begin and end a sacrifice. This presumably led the Vedic Indian to turn to astronomy. The winter and summer solstices formed the basis of their seasonal calculations. The ascertained solstice days almost always coincided with the full moon, new moon, or last quarter of the lunar month. The seasons were calculated beginning from the *uttarayana*-the winter solstice or the first day of the sun's northerly course. There were six seasons, each of two months: winter, spring, summer, rains, autumn, and dews.

Early researchers came across a Vedanga tradition about the position of the solstices of the Vedic period. It states that the sun turns north at the beginning of the Dhanistha division and south at the middle of the Aslesa division-a phenomenon which is known to have prevailed during the period between 1400 and 1200 B.C. This led them to consider this period as the earliest phase of the Vedic age.

The manner in which positions were ascertained in the Vedic period may be determined from a passage in the *Aitareya Brahmana* which indicates that the sun remained stationary at the rising point or maintained the Same meridian zenith distance for twenty-one days at the solstices. The true solstice day was the middle of these twenty-one days. The twenty-one days in which the sun remained stationary at the solstice were divided into ten, one, and ten days. The two periods of ten days at the beginning and at the end were styled *viraja.* Since at the end of the sun's northerly course the sun's rising point remained stationary for twenty-one days, it was thought that the middle or the eleventh day was the true summer solstice day. Similarly, the eleventh day of the solstice at the end of the sun's southerly course was the winter solstice day. When the solstice day fell on a new moon day, the new moon *naksatra* gave the position of the solstitial point. Likewise, when the solstice day fell on a full moon day, the moon's *naksatra* gave the position of the opposite solstitial point. The observation of the retardation in the moonrise after the full moon could exactly settle the full moon day and also perhaps the instant of the full moon. Similarly, the observation of the entire period of invisibility of the moon after the new moon led to the correct estimate of the exact day and perhaps of the hour of the instant of the new moon.

The observation of the phase of the moon on the solstice day settled the nature of the Vedic calendar, whether the lunar months were to be reckoned as ending with the full moon, the new moon, or even with the last quarter of the lunation. Sometimes after four years the months ending with the full moon and starting from the winter solstice day were changed into months ending with the new moon. Hence in the observational methods forming the Vedic calendar, this procedure of changing the system of reckoning lunar months from months ending with the full moon to those ending with the new moon and *vice versa* was quite possible.

A winter solstice on a full moon day in the month of Magha (January-February) will in six years fall on the seventh day of the dark half of the month, and the first day of the sun's northerly course will fall on the next day, i.e. the day of the last quarter. This idea is supported by the statement the first day of the next year will fall on the day of the last quarter in the *Taittiriya Brahman.* In those days the lunar phase of the solstice day gave the mode of reckoning the coming lunar months. In ordinary calendars it was generally preferred to follow the lunar months ending with either the new moon or the full moon. Sometimes there arose a special necessity for finding the winter solstice day of a particular year, which led to the determination of the new phase of the moon for finding the first day of the new year. This settled the dates for beginning the Vedic sacrifices lasting two or four lunations. Among the sacrifices th*e jyotistoma* and *vajapeya*-the spring and the summer sacrifice respectively-were of two months duration each. The four-monthly *(caturmasya)* sacrifices lasted the four months of spring and summer. For these, both the solstice days were very frequently determined in the process mentioned above. The *Aitareya Brahmana*, however, speaks of only the summer solstice day. The year-long sacrifices, like the *asvamedha* and *rajasiiya* began from the spring and lasted twelve lunations. The beginning of spring was taken at 60 or 61 days after the winter solstice day, which was a fair approximation.

The long-period sacrifices performed by the Vedic people sometimes extended to three, five, or twelve years. In three yeah there was evidently one additive lunar month, while in five years there were two. Thus in eight years three additive months had to be reckoned with. Consequently in four years there were one and a half additive months and in twelve years four and a half additive months. The Srautasutras also speak of sacrifices which lasted for thirty-six years or even longer periods.

The Vedic people were keen observers of the motions of the moon amongst the fixed stars. The ecliptic stars were regarded as so many milestones for the moon's motion in a sidereal month. The stars and star clusters about the ecliptic were probably named and reckoned as twenty-seven or twenty-eight, the period of revolution of the moon being between twenty-seven and twenty-eight days. In the *Mahabharata* the *naksatras* are stated to be twenty-seven in number when Rohini is the first star, a phenomenon which may be dated at about 3000 B.C. Many are the *naksatras* mentioned in the *Rg-Veda* but we cannot be definite whether all the twenty-seven or twenty-eight *naksatras* were recognized before the time of the *Taittiriya Samhita (c.* 2446 B.C.). Of the twelve signs of the zodiac, the *Rg-Veda* refers to Mesa (Aries) and Vrasabha (Taurus). But it may be doubted if such references really point to anything similar to the signs of the zodiac as conceived by the ancient Babylonians and Greeks. The twelve signs of the zodiac do not figure in the whole of the Sanskrit literature prior to A.D 400. In the *Mahabharata* there is no mention of the signs of the zodiac. Neither are the days of the week mentioned in the *Mahabharata* or the Vedas. Each day of the lunar month was named after the star or constellation with which the moon was conjoined on that particular day.

In the *Aitareya* and *Kausitaki Brahmanas* we have a detailed description of the *gavamayana* sacrifice. The rules of this sacrifice prescribed the sacrificial days of the year: 180 each for the northerly and southerly courses of the sun. The six extra (*atiratra*) days were not regarded suitable for ordinary sacrifices. These *atiratra* days were distributed through the year at different intervals, resulting in varying calculations of the lengths of the sun's northerly and southerly courses during the Vedic period. Both the summer and winter solstice days could probably be determined in the earliest phase of the Vedic period. In the later phase, however, only the winter solstice day used to be determined. Although the term *gavamayana* means ‘motion of rays’, it really implies the two courses of the sun’s apparent motion. These courses are of equal duration when the sun’s apogee or perigee coincides with either the summer or the winter solstitial point. The approximate date on which such a conjunction might have taken place is A.D 1266.

1.1.3.2. Post-Vedic Astronomy

This section will discuss the development of Indian astronomy from A.D 100 to 500. According to tradition, Vrddha Garga was the earliest Indian astronomer. His name is found in the *Mahabharata*. When the *Mahabharata* in its present form was compiled (4th Cent. A.D), Vrddha Garga had already come to be regarded as a great Indian astronomer who had lived many centuries earlier. Another astronomer was Lagadha, author of the *Yajusa-jyotisa* who discovered that the summer solstice passed through the middle of the *naksatra* Aslesa and the winter solstice through the first point of the *naksatra* Dhanistha. He was followed by Garga and Parasara who carried on his tradition as regards the solstices. We learn from Bhattotpala’s commentary on the *Brhat-samhita* that in Garga’s time the sun turned north before reaching the *naksatra* Dhanistha and in Parasara’s time before reaching the *naksatra* Sravana. It is thus clear that Garga lived after Lagadha, and Parasara after Garga. Parasara lived very probably in the third century A.D. Among other astronomers mentioned in Bhattotpala’s commentary are Rsiputra, Kapilacarya, Kasyapa, and Devala. But there are no indications as to when they lived or what they achieved in the field of astronomy.

Varahamihira’s (A.D 550) *Panca-siddhantika* is the only available work to throw light on the development of astronomy during this period. In this work Varahamihira summarizes the teachings of the *Paulisa, Romaka, Vasistha* and *Paitamaha-siddhantas,* and improves upon the *Surya-siddhanta* by incorporating the astronomical constants from the *ardharatrika* system of Aryabhata I. Varahamihira states his opinion of the five *Siddhantas.* The *Paitamaha-siddhanta,* considered to be the most inaccurate of the five *Siddhantas* is described in the *Panca-siddhantika* in five stanzas. The first one contains all the astronomical constants. According to the *Paitamahay* five years constitute a *yuga* of the sun and the moon. The *adhimasas* are brought about by thirty months, and an omitted lunar day by sixty-two days. In five years there are sixty solar months; and hence, according to this rule, in five years there are two *adhimasas* or additive lunar months. The number of lunar months is sixty-two; thus the number of *tithis* is 1860, which, when divided by sixty two, gives the number of omitted lunar days as thirty. These are the same as in the *Vedanga-jyotisa.* The remaining four stanzas give rules for the use of these elements in calculating (a) the number of civil days elapsed from the light half of Magha of 2 Saka era, (b) the sun’s *naksatra* (c) the moon’s *naksatra* and (d) the number of *vyatipatas* elapsed of the current *yuga. It* also notes that the shortest day was of twelve *muhurtas* and the longest day of eighteen *muhurta* and shows a rough method of finding the length of any given day in *muhurtas*.

The *Paitamaha-siddhanta* does not treat of any other planets. The *Vasistha-siddhanta* (A.D 300), the oldest of the five, is discussed in Chapters II and XVIII of the *Panca-siddhantika.* From this discussion we deduce that the solar year was perhaps taken to consist of 365-366 days nearly. It is thus clear that considerable progress was made at the time in more correctly determining the luni-solar astronomical constants. The courses of the planets are treated in the following order: Venus, Jupiter, Saturn, Mars, and Mercury. These planetary courses relate to the direct motion, stationary stage (*anuvakra*), retrograde motion (*vakra*), and again the direct motion, and are given in the *Panca-siddhantika*. From the determination of these courses, the celestial longitudes of the planets could be calculated.

The *Vasistha-siddhanta* gives rough rules for finding the *lagna* or ecliptic point on the eastern horizon and furnishes the synodic periods in days of the five planets as follows: Venus, 584, Jupiter-399, Saturn-378, Mars-780, and Mercury, 115 day 52 *nadikas* 45 *vinadikas.* In using the signs of the zodiac in place of *naksatras,* the *Vasistha-siddhanta* represents the oldest system of Babylonian astronomy as transmitted to India. Chapter II of the *Panca-siddhantika* states the rules for calculating the length of the day as follows: The shortest day is 26 *nadikas* 31 *palas* in length; from the shortest to the longest, the days are thought to increase by 3 *palas* every day. This rough rule is on a par with those given in the *Vedanga-jyotisa* and *Paitamaha-siddhanta.* The other rules for finding the longitudes of the moon and sun and the shadow of the gnomon at midday are also inexact. No definite method for the calculation of eclipses occurs up to the time of the *Vasistha-siddhanta*. The *Paulisa-siddhanta,* according to Varahamihira, maintained that there are 43,831 days in 120 years. Thus the length of the year was taken to be 365-2583 days. The longitude of the sun's apogee was taken to be 80°. The mean measure of this periphery of the sun's epicycle was considered to be about 15°8, which is near to that accepted by Ptolemy, viz. 15°. However, the faulty text of this *Siddhanta* prevents us from forming any idea of its views about the mean motion and the equations of the moon. As regards the moon's other elements, the author of the *Paulisa-siddhanta* knew of the same two convergent to the anomalistic month, viz. 248 days, as was known to the author of the *Vasistha-siddhanta.* According to the *Paulisa-siddhanta*, the moon's greatest latitude was 270' or 4° 30', as in all other *Siddhantas*. The courses of the planets Mars, Mercury, Jupiter, Venus, and Saturn as given in the *Paulisa-siddhdnta* are found in the latter portion of Chapter XVIII of the *Panca-siddhantika*.

The *Romaka-siddhanta* as summarized by Varahamihira in his *Pancasiddhantika* bears a foreign name and represents perhaps the sum total of Greek astronomy transmitted to India. According to Varahamihira, the luni-solar *yuga* of the *Romaka-siddhanta* comprises 2,850 years in which there are 1,050 *adhimasas* and 16,547 omitted lunar days. From this it is inferred that there are 1,040,953 civil days and 3,520 synodic months in 2,850 years. The year thus consists of exactly 365 days , as accepted by Ptolemy. The *Romaka* synodic month agrees more closely with that of the *Aryabhatiya*, according to which its length is equal to 29.530582 days The length of the anomalistic month is expressed as 3031 days, i.e. 27.554 days. It is evident that in respect of the lengths of the synodic and anomalistic months the *Paulisa* and *Romaka-siddhantas,* and the *Aryabhatiya* are very nearly in agreement.

In the *Romaka-siddhanta* the revolutions of the moon's nodes are stated to be 24 in 163,111 days. One revolution thus takes 6,796 days and 7 hours. This figure according to Ptolemy is about 6,796 days and 11 hours, while Aryabhata puts it at 6,794-749511 days. The rule for parallax in longitude is the same as in the *Paulisa-siddhdnta.* The rule for parallax in latitude is expressed in the following equation. The greatest latitude of the moon is taken in the *Romaka-siddhdnta* to be 270', as in all the *Siddhantas*. According to Ptolemy, however, this is about 5° or 300'. The mean semi-diameters of the sun and the moon are recorded as 15' and 17' respectively, while Ptolemy states them to be 15'40' and 17'40'.

Aryabhata: Scientific Indian astronomy dates from the year A.D 499 when Aryabhata I of Kusumapura (Pataliputra or Patna) began to teach astronomy to his pupils. Amongst his direct pupils, mention may be made of Pandurangasvamin, Latadeva, and Nihsanka. One Bhaskara, whom we shall refer to as Bhaskara I, was perhaps also a direct pupil of Aryabhata I ; or he might have been a pupil of his direct pupils. Bhaskara I was the author of the *Laghubhaskariya* and the *Mahabhaskariya* which treat of Aryabhata's system of astronomy. He also wrote a commentary on the *Aryabhatiya*. He is mentioned by Prthudaka in his commentary on the *Brahmasphuta-siddhdnta* of Brahmagupta. Among the direct pupils of Aryabhata I, Latadeva, expounder of the old *Romaka* and *Paulisa-siddhanta* got the appellation of *sarva-siddhanta-guru,* i.e. teacher of all the systems of Siddhantas. Aryabhata I was original in the construction of his new science. He was the author of two distinct systems of astronomy, the *audayika* and the *ardharatrika*. In the first, the astronomical day begins at the mean sunrise at Lanka, and in the other, it begins at the mean midnight.

The *Aryabhatiya* teaches the *audayika* system, and *ardharatrika* system. A comparison of the astronomical constants of the Greek and the Indian systems points unmistakably to the conclusion that the Indian constants determined by Aryabhata I and his successors are in almost all cases different from those of the Greeks.

Aryabhata teaches his theory of planetary motions as follows: 'All planets move in eccentric orbits at the mean rates of angular motion, in the direction of the signs of the zodiac from their apogees (or aphelia) and in the opposite direction from their *Sighroccas.* The eccentric circles of planets are equal to their concentric, and the centre of the eccentric is removed from the centre of the earth. The distance between the centre of the earth and the centre of the eccentric is equal to the radius of the planet's epicycle; on the circumference (of either the epicycle or the eccentric) the planet undoubtedly moves with the mean motion.

With regard to the five superior planets-Mercury, Venus, Mars, Jupiter, and Saturn-Aryabhata I and other Indian astronomers give only one method for finding the apparent geocentric position. Each of these 'star planets' is believed to have a twofold planetary inequality: (i) the inequality of the apsis and (ii) the inequality of the *sighra.* With regard to the superior planets, the *sighra* apogee or the *sighrocca* coincides with the mean position of the sun.

The theory of spherical astronomy of Aryabhata I is contained in the *Golapada* section of the *Aryabhatiya.* Aryabhata I explained the methods of representing planetary motions in a celestial sphere. Such terms as prime vertical, meridian, horizon, hour circle, and equator are defined in this section. Aryabhata I was the first Indian astronomer who referred to the rotation of the earth to explain the apparent diurnal motions of the fixed stars.

Varahamihira's redaction of the old *surya-siddhdnta* is a wholesale borrowing from the *ardharatrika* system of astronomy of Aryabhata I. But, his work is valuable from the viewpoint of the history of Indian astronomy. He mentions the names of the following astronomers who preceded him: Lajadeva, who was a direct pupil of Aryabhata I; Simhacarya, of whom we know very little except that he considered the astronomical day to begin from sunrise at Larika; Aryabhata I; Pradyumna, who studied the motions of Mars and Saturn; and Vijayanandin, who made special observations of the planet Mercury.

Brahmagupta (b. A.D 598) wrote his *Brahmasphuta-siddhdnta* in *c.* A.D 628 and his *Khandakhadyaka* in A.D 665. The second work gives easier methods of computation of the longitude of planets according to Aryabhata's *ardharatrika* system of astronomy. In his first work he has corrected all the erroneous methods of Aryabhata I and has in more than one place corrected the longitude of the nodes, apogees, and other astronomical elements of planets. Indeed, after Aryabhata I the next name of significance is undoubtedly Brahmagupta, who, coming 125 years after the former, did not find much scope for the further development of Indian astronomy. Thus being jealous of the great fame of Aryabhata I, he made some unfair criticisms of his work. Besides his corrections of Aryabhata's system. In his *Khandakhadyaka* he demonstrated the more correct method of interpolation by using the second differences. Indeed, his methods have been accepted by all the subsequent famous astronomers like Bhaskara II and have been incorporated into redactions of the *Siddhantas.*

1.1.3.3. The Originality of Indian Astronomy

Concepts of scientific astronomy in India were not borrowed wholesale from cither Babylonian or Greek science rather the ancient *sutrakaras* or writers of aphorisms who stated only their results but not the methods by which they obtained them. These methods were at first transmitted through generations of teachers, and in the course of ages they were lost. Aryabhata I furnished only one stanza (*Golapada*) regarding his astronomical methods, which says: 'The day-maker has been determined from the conjunction of the earth (or the horizon) and the sun; and the moon from her conjunctions with the sun. In the same way, the "star planets" have been determined from their conjunctions with the moon.' No other Indian astronomer has left us anything of the Indian astronomical methods. There is no doubt that Greek astronomy came to India before the time of Aryabhata I. Varahamihira has given us a summary in his *Panca-siddhantika* of what was known by the name of the *Romaka-siddhanta*, but nothing of the epicyclic theory is found in it. A verbal transmission of that theory together with that of a few astronomical terms from a foreign country was quite possible. It must be said to the credit of Indian astronomers that they determined all the constants anew. The Indian form of 'evection equation' is much better than that of Ptolemy and stands on a par with that of Copernicus. It is from some imperfections also that this originality may be established. For instance, the early Indian astronomers recognizcd only one part of the equation of time, viz. that due to the unequal motion of the sun along the ecliptic. In regard to the methods of spherical astronomy, the Indian astronomers were in no way indebted to the Greeks. The Indian methods were of the most elementary character, while those of

Ptolemy were much advanced and more elegant. Yet the Indian astronomers could solve some problems where Ptolemy failed. For instance, they could find the time of day by altitude and the altitude from the sun's azimuth. Thus, although scientific Indian astronomy is dated much later than the time of Ptolemy, barring the mere idea of an epicyclic theory coming from outside India, its constants and methods were all original.

1.1.4. Medicine: Ayurveda

Ayurveda, the traditional system of Indian medicine, is a special branch of knowledge on life dealing with both body and mind. This is implicit in the two components of the term *ayurveda*: *dyus* and *veda.* The former means 'life', and the latter, 'knowledge' or more precisely 'science'. According to the *Caraka-samhita*, *dyus* comprises *sukha* (happiness), *duhkha* (sorrow), *hita* (good), and *ahita* (bad). *Sukhamayuh* or a life of happiness is free from physical and mental disease; endowed with vigour, strength, energy, and vitality; and full of all sorts of enjoyment and success. *Asukhamayuh* or a life *of duhkha* is just the opposite. Ayurveda deals with these four conditions of life. It is also concerned with the prolongation of life.

1.1.4.1. Scope of Ayurveda

The scope of Ayurveda is not limited to physical health alone. It also seeks to promote a totality of physical, mental, and spiritual health in the context of man's interaction with his environment. Ayurveda is concerned with the origin of life and intelligence which are eternal. The wide scope of Ayurveda, in general, covers (i) cosmological and ontological speculations about the intrinsic relationship between matter and life; (ii) biological theories concerning (a) embryonic conception, (b) body, life, and soul, and (c) rules of genetics; (iii) physiological and pathological theories; (iv) food; (v) rules of health and longevity; (vi) diseases, their diagnosis and treatment; (vii) poisons and antidotes; and (viii) ethics.

1.1.4.2. Origin and antiquity

Origin: The origin and antiquity of Ayurveda have been examined from two considerations; one is myth and tradition; and second is historical analysis. Tradition has it that Ayurveda is of divine origin from Brahma who later on communicated this knowledge to the Asvins, and from the twin divinities it came to Indra. Its human tradition began with the transmission of this divine knowledge to two mythical personages, Bharadvaja and Dhanvantari, who in their turn were responsible for the two streams of Ayurveda, i.e. medicine and surgery. Traditionally, Bharadvaja specialized in both medicine and surgery. It therefore appears that the two streams originated not from two persons but from one under two appellations. This is corroborated by the association of Dhanvantari with his incarnated name Divodasa and subsequently with Bharadvaja in the *Rg-Veda* and later Vedic texts. It is also believed that their two successors, Aitreya and Susruta, were not two different persons, Susruta, alias Bahusruta, meaning 'an extremely learned person'. The divine origin of Ayurveda has been mentioned by Caraka and Susruta as well as by later authorities. Possibly some common sources were relied upon by these two medical authorities in this regard. Caraka holds this divine knowledge of Ayurveda as eternal, but considers it to have a beginning from its first systematized comprehension or instruction.

While tradition would have us believe in the eternity of Ayurveda, historical considerations lead us to trace its origin to pre-Aryan times. In fact, different streams of thought and ideas are found to have been incorporated through ages in the various branches of Ayurveda. Its medical corpus is an extension and systematization of earlier medical knowledge of the pre-Aryan and Indo-Aryan peoples. Its philosophical speculations and logical deliberations in the understanding of the creation of the world in the context of material components of the body and in finding out the aetiology of diseases are borrowed from different philosophical systems, particularly the Samkhya and the Nyaya-Vaisesika. These contributed to the development of Ayurveda as we have it today.

Pre-Aryan Medical Elements: Archaeological remains concerning pre-Aryan medical elements unearthed from different sites of Indus and pre-Indus cultures testify to rudimentary ideas about some medical and surgical practices. Surgical activities are inferred from trephine human skulls and curved knives from two pre-Indus sites, viz. Burzahom in Kashmir and Kalibangan in Rajasthan. Medical practices inclusive of some health and hygienic measures are indicated in excavations at Mohenjodaro and Harappa.

These comprise elaborate sanitary measures, arrangements for bath in specially-built chambers, and medicinal substances consisting of stag-horn, cuttle-fish bone, and bitumen. The craniotomic operation described in the *Susruta-samhita*, hygienic rules and regulations as part of medical practice, application of vapour bath in medical treatment, and utilization of animal and mineral substances in medical prescriptions are some of the instances of borrowing by the Ayurvedic system from earlier cultures.

Indo-Aryan Medical Elements**:** While pre-Aryan elements led to the development of some medical practices in Ayurveda, Indo-Aryan medical elements facilitated the growth of some concepts and theories. These are mainly noticed in (a) cosmo-physiological speculations about the three basic constituents of living organisms, viz. *vayu*, *pitta*, and *kapha*; (b) ideas about the aetiology of diseases; and (c) belief in the association of medical treatment with god physicians.

(a) Cosmo-physiological speculations relate to the humeral theory of Ayurveda which propounds that wind *(vayu)*, bile *(pitta)*, and phlegm *(kapha)* are the three basic elements activating, sustaining, nourishing, and maintaining the life-principle. The origin of this theory may be traced to Indo-Aryan speculations regarding the three world-components, viz. air, fire, and water, which similarly sustain, maintain, and motivate the world. The cosmic element of *vayu* or *vata* (air) is considered the motor *par excellence* which activates the entire universe. Its physiological manifestation is the vital breath or *prana* which, according to Ayurveda, regulates all functions of life. *Pitta*, which maintains the thermal balance of the body, is a manifestation in living organisms of the cosmic principle of *agni* (fire). The term *kapha*, meaning that which results from water, corresponds to the cosmic primordial water *(ap).* This primordial element was viewed by both the Indo-Aryans and Indo-Iranians as 'mother', as a 'vivifying liquid' (nectar). Some other epithets show it as the 'fluid matrix' from which the birth of living organisms was possible. Its physiological element *kapha* in the human body is also credited with the same properties. Both *ap* and *kapha* signify the fluid-matrix in which all the operations of life are possible.

(b) Ayurvedic theories and ideas about the aetiology of diseases are of two kinds, rational and irrational. The first kind is formulated on the basis of pathological conditions, while the second is rooted in the notion of superhuman and malefic agencies being the cause of diseases. Maladies classed under the second group are known as *adhidaivika.* Ayurveda owes much to the Indo-Aryan or Vedic medicine for this idea of the irrational cause of diseases. Moreover, the elaborate theory of *dosas*, i.e. abnormal conditions of the three basic elements as the main cause of disease, which developed in Ayurveda, is also suggested in a passage of the *Atharva-Veda*.

(c) The other Indo-Aryan element present in Ayurveda is the association of godheads with medical treatment. The important god-physicians of the Vedic medicine finding prominence in Ayurveda were Brahma, Indra, Rudra (as Siva), Surya or Agni, and the two Asvins. Their active role as physicians in the Vedas is replaced by the Ayurvedic medical formulae which allude to different godheads for the cure of specific diseases. This association of divinities with healing was a common aspect of ancient medicine throughout the world. The authors of Ayurveda in order to glorify the medical prescriptions appear to have associated them with the renowned Indo-Aryan god-physicians.

Ayurveda and the Vedas: In its conceptual aspects Ayurveda has greater affinity to Rg-Vedic notions, while in practice it draws much from Atharva-Vedic medicine. Its relation to the *Atharva- Veda* is seen in its (i) two fold objective of the curing of disease and the attainment of a long life; and (ii) anatomical and physiological ideas. Under the second category may be cited (a) three types of bodily channels-*hirdy dhamani,* and *nadi*-used in the sense of duct in the *Atharva-Veda* and corresponding to *Hrady, dhamani*, and *nadi* of Ayurveda which mentions an additional channel (*srotas);*(b) ideas of five vital breaths common in the two systems;(c) osteological ideas in connection with the number and nomen- clature of bones; and (d) *ojas* (albumen), the vital element in the body recognized in Atharvan medicine and in Ayurveda.

The main points of difference between Ayurveda and the *Atharva-Veda* are in the concept and mode of treatment of diseases. The *Atharva-Veda* stresses the wrath of gods and influence of malefic agents as the causes of diseases more than imbalances in bodily elements which are given primary importance in the diagnosis of diseases in Ayurveda. Hence drug treatment predominates in Ayurveda whereas treatment by charms is emphasized in the *Atharva-Veda*. Ayurveda, which incorporates different traditions, has a distinct place alongside of the Vedas. It forms a *upanga* of the *Atharva-Veda* and *upaveda* associated particularly with the *Rg-Veda.* It is sometimes called a *panchama-veda* or fifth Veda. The epithet *upanga* is presumed to have come into use on account of the resemblance between Ayurveda and the medical portion of the *Atharva-Veda.* This relationship has been noted by Susruta himself and later on by others. Its appellation as a *upaveda* or minor Veda of the *Rg-Veda* occurs in the *Caranavyuha*. Ayurveda is mentioned as a fifth or distinct Veda in the *Brahmavaivarta Purana*. Modern writers consider it as a Vedanga or an appendage of Vedic literature. All the aforementioned epithets of Ayurveda point to its existence in some form during the composition of Vedic literature. Although glorified as an appendage of Vedic literature, Ayurveda as such is not mentioned there. A later Vedic text designates a medical treatise as *subhesaja*. The *Mahabharata* first refers to Ayurveda with its eight branches of knowledge. It specifically mentions Ayurveda composed by Krsnatreya.

1.1.4.3. Development and Decline of Ayurveda

Ayurveda as systematized into eight parts appears to have developed abruptly, but this impression is due to paucity of written records concerning the early state of Ayurveda. These early treatises were superseded by the present recessions because of their growing popularity. A list of the early recessions is preserved, however, in the *Brahmavaivarta Purana*. The history of Ayurveda may be divided into four stages,; first, the beginning period **(***idevakala*), second, the period of compilations *(rsikala* or *samhitakala)*, thirdly, the period of epitomes (*sangrahakala*), and finally, the period of decline. These four periods are marked by three distinct types of Ayurvedic treatises.

***Beginning Period*:** In this period Ayurvedic works were attributed to mythical, divine, and semi-divine, personages. These works are all lost. Important among them were the *Brahma-samhita* composed of 100,000 *Mokas*, *Prajapati-samhita*, *Alvi-samhita*, and *Balabhit-samhita*.

***Period of Compilations*:** This period (c. 500 B.C-A.D. 500) witnessed the compilation of the works of ancient teachers who were the founder-writers of different aspects of Ayurveda. These aspects or eight parts of Ayurveda include Kayacikitsa (therapeutics), Salya-tantra (major surgery), Salakya-tantra (minor surgery), Bhutavidya (demonology), Kaumarabhrtya-tantra (pediatrics), Agada-tantra (toxicology), Rasayana-tantra (geriatrics), and Vajikarana-tantra (virilification).

(i) Kayacikitsa relates to treatment of diseases affecting the whole body, which are supposed to originate mainly from disturbances of the three humours. The first and foremost compilation was the *Agnivela-tantra* of Agnivesa, based on the teachings of Atreya Punarvasu. This work dealt primarily with therapeutics but touched upon other aspects of Ayurveda excepting *talakya.*

(ii) Salya-tantra *(Salya* literally means 'arrow') deals with the methods of removing foreign bodies; obstetrics; the treatment of injuries and diseases requiring surgery; and the use of surgical instruments, alkalis, bandages, etc. The *Susruta-samhita* is one of the great classics on Indian surgery, belonging to the Divodasa-Dhanvantari school.

(iii) Salakya-tantra is concerned with the treatment of diseases of the body above the clavicle and use of thin bars, small sticks or probes, etc. as instruments. The nine texts belonging to this group, viz., *Videhanimi-*, *Kankayana-*, *Gargya-*, *Galava-, Satyaki-*, *Saunaka-, Karala* and *Krsnatreya-tantras*, are all lost.

(iv) Bhutavidya treats of mental derangements and other disturbances said to be caused by demons and prescribes prayers, oblations, exorcism, drugs, and so forth as remedies. No separate works appear to have been composed on this branch of Ayurvedic medicine. But various chapters devoted to this subject found in larger works include the *Amanusapratisedha adhyaya* of the *Susruta-samhita* and *Unmadaniddna adhyaya* of the *Caraka-samhita*.

(v) Kaumarabhrtya-tantra gives methods of treatment of child diseases caused by demons. Works in this branch, which are all extinct today, dealt with both child and female diseases. These included the *Jivaka*, *Paravataka* and *Hiranyaka-tantras.*

(vi) Agada-tantra discusses methods of diagnosis and treatment of the bites of poisonous snakes, insects, etc. and of herbal or other poison cases. Works on this branch of Ayurveda mentioned in the commentaries on *Susruta* and *Caraka.*

(vii) Rasayana-tantra deals with methods of preservation and increase of vigour, restoration of youth, improvement of memory, and prevention of diseases. Works on this subject referred to in commentaries and works on alchemy are the *Sadhana-tantra*; and the *Nagaijuna-tantra*, all of which are lost.

(viii) Vajikarana -tantra concerns the means of increasing virile powers. The known texts on this aspect of Ayurveda, now lost, were the *Kucumara-tantra*, *Agastya-samhita*, and *Kaupalika-tantra.*

Period of Epitomes**:** The Sangrahas, appearing from about the seventh century onwards, were epitomes of earlier texts. These summaries were of two types: complete and partial. On this aspect, the eight complete texts extant today. Partial summaries include numerous works relating to aetiology, treatment of particular diseases, science of pulse, diabetics, etc. Some of the extant works of prominence are *Arkaprakara* of Ravana, *Cikitsasara-sangraha* of Cakrapanidatta, *Navanitaka* of Srikanthadasa, and *Rajamartanda* of Bhoja.

Period of Decline**:** The decline of Ayurveda began in the period of the Sangrahas when medical authorities started summarizing the classics and codifying them as separate treatises. This process accelerated in the post- Sangraha period with the total absence of new redactions, commentaries, etc. The disappearance of ancient Samhitas made the later Sangrahas faulty. The decadence of Ayurveda is believed to have been caused by the following factors:

(i) disappearance of the practice of dissecting dead bodies, which resulted from either Buddhist influence in the seventh and eighth centuries A.D. or disturbed political conditions or lack of encouragement and patronage by Muslim rulers, producing an increasing number of poorly trained Ayurvedic physicians; (ii) lack of facilities for clinical studies due to want of hospitals during the medieval period; (iii) growing popularity of Unani medicine under the patronage of Muslim rulers; and (iv) popular apathy to the Ayurdevic system.

1.1.4.4. Application of Ayurveda to other forms of life

Ayurvedic theories and practices were also applied to animal and plant life. There are voluminous medical treatises on plant life (Vrksayurveda), horses (Avayurveda), elephants (Hastyayurveda), and the bovine species (Gavayurvcda). Besides these, general books on medicine also contain some portions dealing with veterinary science. The *Togasudhanidhi* of Vandimisra contains a chapter on conception, obstetrics, and special diseases of female animals. The principal work on Asvayurveda is the *Salihotra-samhita* of uncertain date. The *Salihotra-samuccaya* of Kalhana (i*c*. twelfth century A.D.) is believed to be a redaction of the *Salihotra-samhita.* It is a volumnious work in sixty-eight chapters throwing light on different aspects of the horse inclusive of anatomy, physiology, and pathological conditions requiring medical and surgical treatment and including information relating to breed, sex, age, and so on. The medical and surgical methods follow the classical precepts of Ayurveda. Other works were the *Ahavaidyaka* by Jayadattasuri and *Ahasastra* by Nakula. The latter was known for its illustrations of horses and knowledge of equine anatomy. Another work, the *Cikitsa-sangraha*, contains a glossary of terms. The extant exhaustive treatise on Hastyayurveda, the *Palakapya-samhita* attributed to sage Palakapya, is a voluminous work deals with anatomy, physiology, pathology, major and minor diseases with medical and surgical treatments, and drugs and diet.

A treatise on Gavayurveda attributed to Gotama was presumably extant until the Middle Ages as quotations from it occur in the *Rajamartanda*. Apart from diseases and their treatment, the text contained information on diet, breeding, calving, lactation, and milk. The importance of Vrksayurveda may be assessed from discussions on this subject in works like the *Arthasastra*, *Brhat-samhita*, *Agni Purana* and *Visnudharmottara Purana.* The information contained in these texts mostly relates to sowing and germination of seeds, manuring, growth, classification of plants, and their treatment in diseased conditions. The two available works on this branch of knowledge are the *Vrksayurveda* of Surapala (*c*. tenth century A.D.) and the *Sarngadhara-samhita* (*c*. fourteenth century A.D.) , a medical compendium containing a chapter called *Upavana-vinoda* which deals with different aspects of plant life and concentrates on the aetiology, diagnosis, and treatment of plant diseases. Surapala's work adopts the theory of *tridosa* in the diagnosis and treatment of internal diseases of plants.

1.1.4.5. Later Development of Ayurveda

A new type of Ayurvedic treatment, *rasacikitsa*, which incorporated iatrochemistry or metallic compounds, came into vogue from *c.* A.D.1300. It sought to utilize bodily fluids *(rasa)* for repelling diseases and preventing senility, and thereby acquiring a long life. Numerous preparations of mercury, iron, copper, and other metals as formulated in alchemy were found to be helpful accessories in medicine. At first they were used cautiously and tentatively in combination with the recipes of Caraka and Susruta mainly based on medicinal plants. Later, these preparations supplanted the old Ayurvedic herbal treatment. Mercury became a principal healing substance, of which numerous preparations are described in different iatro-chemical texts and even in general works on Ayurveda of the medieval period. Opium and several other foreign drugs were incorporated into Ayurvedic pharmacology in about A.D.1500. Mineral acids, tinctures, and essences also came to be used about the same time.

1.1.4.6. Spread of Ayruveda Outside India

The concepts and theories of Ayurveda have their parallels in the contemporary medical systems of Iran, Hellenic countries, and Mesopotamia. The influence of Ayurveda on Greek medicine is noticed particularly in respect of the theory of pneuma physiology. Both recognize the importance of wind as the propeller of all movements in the body inclusive of fluid circulation; as the cause of many diseases, particularly those of the nervous system; in building up the anatomy and physiology of the foetus from the moment of conception; and in the circulation of the mother's vital breath through the embryo. Apart from the pneuma theory, the Ayurvedic concept of humoral origin of diseases also occurs in Hippocratic manuals, but the treatment is less sophisticated. It is reasonable to conclude that these ideas 'were imported into Greece along with many other Ayurvcdic concepts'. The medical treatment of eye diseases of elephants referred to by Megasthenes (*c*. fourth century B.C.) is found to have been based on ideas borrowed from the *Hastyayurveda* of Palakapya. The use of drugs like dry *pippali* (long pepper) as a cure of eye diseases, and many other facts and logical inferences show that Ayurveda spread into Greece. Conversely, some ideas associated with Greek medicine might have been incorporated in Ayurveda.

The spread of Ayurveda in Hellenic countries is to some extent inferred, but in the case of Arab countries and other parts of the world it is evident as Ayurvcdic texts or their translations are found there. Some renowned Ayurvedic texts were translated into Arabic and from Arabic into Persian. The *Susruta samhita* was translated by an emigrant Indian physician under the title of *Kitab-Samural-hind-i.* Ali ibn Zain translated the *Caraka-samhita* under the title of *Sarag.* The *Astangahrdaya* was translated as *Astankar* and the *Mddhava-nidana* as *Badan.* Ayurveda thus came to be a well-known science in Arabia from where it spread into Persia. There is evidence of the spread of Ayurvedic concepts and facts in Iran, Central Asia, Tibet, Indo-China, Indonesia, and Cambodia. Several Ayurvedic texts have been found in Central Asia.

1.1.5. Engineering and Architecture in Ancient India

The achievements of Indian people in the field of engineering began in the proto-historic times, from the third millennium B.C. or even earlier. The ancient Indian civilization like those of Iran, Iraq, Mesopotamia, and Egypt showed skill in the construction of buildings and granaries, in town-planning, and in the provision of civic amenities like community baths and other sanitary conveniences.

1.1.5.1. Prehistoric Period:

The earliest evidence of the technical skill of the ancient Indian lies perhaps in the numerous tools he carved out of stone in the course of his struggle for existence. A long period of trial and error requiring power of observation and the application of what was observed in his natural surroundings must have intervened between this period of the fashioning of crude pebble tools and the development of the hand-axe. The early Paleolithic age was followed by the middle Paleolithic age when he made tools on fine-grained flakes, which were smaller in size and included scrapers, points, awls or borers, blades, etc. These tools, archaeologists think, might have been used for dressing animal skins and barks of trees, smoothing the shafts of spears, cutting, chopping, etc. They may be classified into two groups-core and flake-according to the way in which they were made. Core tools were made by chipping or flaking away a stone until the desired shape was obtained. Flake tools were made, however, by detaching a large piece from a stone and then working it into the requisite shape. A third classification put forward by some archaeologists is the chopper-chopping tool group; these tools were made from pebbles by knocking off a portion to make the cutting edge.

The Mesolithic age saw the growth of what is called the small stone microlithic industries of India. At Langhnaj in Gujarat have been discovered pottery and tools as well as sandstone slabs, flattened on one side and used for grinding. The next stage in the growth of man's skill in India is termed the Neolithic revolution when he started settling down, making tools from bones of animals he hunted. Excavations at Burzahom near Srinagar have revealed that the earliest inhabitants of this valley lived in circular or oval pits dug into the *Karewa* soil. Evidence of postholes along the edge of the pits indicated a timber superstructure covered over by a thatched roof. The pit-dwellers provided landing steps to reach down the floor of their house, where stone hearth and small-sized storage pits were met with. In the succeeding period, red ochre was found used as a colouring material for the floor'. Such pit-dwellings have also been found at Nagarjunakonda in the Krishna valley.

1.1.5.2. Architecture during Harappan Period

Remains of the Indus valley civilization (fourth-third millennium B.C.) unearthed at Mohenjodaro and Harappa now in Pakistan, Lothal in Gujarat, and Kalibangan in Rajasthan amply testify to the well-developed technical skill of ancient Indians. Mohenjo-daro in Sind and Harappa in the Punjab are deemed to have been the capital cities of the Indus valley. Each of the towns was approximately three miles in circuit. The dwellers of Mohenjo-daro were among the world's pioneers in city construction. The largest buildings unearthed in Mohenjo-daro measure more than 73 m X 34 m. Road alignments were from cast to west and from north to south, each crossing the other almost at right angles in a chessboard pattern. The width of the roads varied from approx. 10 m. to 5.48 m., depending on the requirements of traffic. There is evidence of attempts to pave the roads at some places.

The houses unearthed are commodious and well built, indicating the civil engineering skill of the people. The bricks were well burnt and of various proportions, such as 1.2.3. The bricks were cast in open moulds by the open stack method with wood fuel to burn them. Although the Indus valley people acquired considerable mastery over brick-making they have left us no evidence of decorative brick work. Most of the houses had more than one floor, although the number of rooms on the first floor was presumably limited. Nevertheless, the technique of load distribution must have been mastered by them. The houses were closely built. The average middle class dwelling was about 9.14 m. X 8.22 m., consisting of four or five living rooms. These houses were constructed with due provision for sanitary amenities. A typical house included a central courtyard; a well-room; a paved bath; a sewer pipe protected by brick work which ran beneath the floor into the public drain in the street, providing drainage from the courtyard; and a pipe running vertically in a wall to carry sewage from the upper floor. The use of a pulley wheel for drawing water from the wells was known as may be inferred from certain depictions in terracotta. Among the ancient remains found in the Indus valley are two remarkable structures, viz. the Great Bath situated in the citadel mound at Mohenjodaro and the Great Granary at Harappa. The overall dimension of the Great Bath is 54.86 m. x 32.91 m., while the swimming pool, situated in the centre of a quadrangle with verandahs on all sides, measures 11.88 m. x 7.01 m. The massive outer walls of the building are 2.13 m. to 2.43 m. thick at the base with a batter on the outside. There are at either end of the swimming pool a raised platform and a flight of steps with another platform at the base of each flight of steps. The pool is lined with finely dressed brick laid in gypsum mortar with an inch of damp-proof course of bitumen. From an analysis of samples of bitumen at Mohenjo-daro.

The Great Granary at Harappa consists of a series of parallel walls, each 15.9 m. long standing in two sections divided by a passage 7. 01 m. broad. The building thus comprises two similar blocks, together measuring 51.51 m.X41.14 m. The walls are about 2.74 m. thick. In each block there are six halls alternating regularly with five corridors. Each of the halls is partitioned into four narrow divisions by three equidistant, full-length walls terminating in broader piers at the ends. The piers are made of burnt brick, while the partition walls are of mixed construction.

The remains of Lothal, nearly 3.2 km. in circumference, remind one of Mohenjo-daro in miniature. The town was more or less designed after the patterns of Mohenjo-daro and Harappa with streets constructed at right angles. An important feature was a thick mud wall, reinforced with burnt bricks on its northern periphery, which served as a defense against floods. The blocks of the town were raised on mud bricks to further provide a degree of security against floods. There is evidence of civic amenities like brick-built wells, underground sewers, cesspools, and brick-paved baths. Among the important structures are a dock with a wharf and a warehouse. The dock is a testimony to the engineering skill of its builders and was the first ever venture made by man to build an artificial basin for sluicing ships at high tide'. In its conception and engineering it surpasses the Roman and Phoenician docks of later times. Its embankment walls measure 212.4 m. on the west, 36.4 m. on the north, 209.3 m. on the east, and 34.7 m. on the south. The basin and walls are lined with burnt bricks. It was built off the main stream in order to reduce the likelihood of silting and flooding, and incorporated a water-locking device and a spillway to ensure floatation of ships during low tide. Ships would enter the dock at high tide. The inner walls were made perfectly vertical so that cargo could be loaded and unloaded directly between the ships and the wharf. The wharf, measuring 260 m. ran along the western wall of the dock. From the wharf goods could be taken to the warehouse adjacent to it. The warehouse had a floor area of 1,930 sq. m., larger than the granaries of Mohenjodaro and Harappa. The structure stood on a 4-metre high platform on which were raised sixty-four blocks of mud bricks, each block 3.6 m. square and 1 m. high. The blocks were interspersed with 1-metre wide passages to allow ventilation and easy access to the goods. On top of the blocks a superstructure of timber was raised.

Archaeologists have found in Kalibangan ruins of a town and a fortified citadel on an artificial platform of mud and mud-bricks six to seven metres high. Though smaller than Mohenjodaro, Harappa, and Lothal, Kalibangan was a well-planned town with houses built in oblong blocks flanking the arterial streets, running in cardinal directions. Lack of street drains suggests that the sanitation of Kalibangan was not as rigorously maintained as in the other Harappa towns and cities. There-were, however, private baths, soakage jars, and drains. Excavations reveal evidence of the use of copper axes, which 'clearly shows the beginning of metallurgy as early as 2450 B.C.'

The Indus valley people thus achieved considerable proficiency in engineering and technical skill, as shown by their use of building materials and their construction of roads, drains, etc. A system of weights and measures was in vogue. Weights found at Mohenjodaro and Lothal are normally of cut and polished cubes of chert. Finds of graduated scales made of shell at Mohenjodaro, of bronze rod at Harappa, and of ivory at Lothal indicate their knowledge of practical geometry and land surveying. The average distance between the successive divisions of the scales is 6.70 mm., 9.34 mm., and 1.70 mm. respectively. Terracotta plumb-bobs and an instrument made of shell for measuring angles of 45°, 90°, and 180° were also found at Lothal.

1.1.5.3. Vedic Period

Whereas the Indus valley civilization was essentially urban, relying on extensive trade and depending upon organized city life for its existence, the Vedic civilization was primarily pastoral or an agricultural one in which complex urban organization was unknown. It is not surprising, therefore, that highly developed cities like Harappa and Mohenjodaro did not appear during the Vedic period and that technology was in evidence only to the extent of providing for the necessities of village life. Vedic texts are replete with words descriptive of dwellings and contrivances which provide an idea of the extent of technological knowledge of the period. The word *pura* occurs frequently in the *Rg-Veda* and later Vedic texts and appears to mean a fort or fortification. Hundred-walled forts arc also mentioned. The term *maha-*

pura (great fortress) appears in the *Taittiriya Samhitd*, *Aitareya Brdhmana*, and other texts. The type of material with which the forts were constructed is not clearly indicated. In all probability they were temporary structures, perhaps merely ramparts of earth with ditches and stone walls, or possibly made of wood. In one place the *Rg-Veda* refers to a fort made of stone (*asmamayi*).

Grha is used to denote a house. The sides of the house were called *paksa* and the door *dvara.* From passages in the *Atharva-Veda*, the following possible method of construction is found. On a good site, four pillars (*upamit*) were set up, against which beams were propped as supports. The pillars were then joined on top by cross beams. Bamboo was used as ribbing over a ridge called. Finally, the ribs were covered with a kind of thatching. The walls were set up with grass tied in bundles which were bound together. Some terms like sitting room and wives' room suggest that the dwellings were compartmented.

References to private dwellings in Grhyasutra texts indicate that spacious houses in the later Vedic period were quite common. An arrangement of water supply was evidently part of house construction. Ponds, wells, and other reservoirs of water are also mentioned in Grhyasutra texts. Some of these were presumably public works meant for general use. There are references to bridges, roads, cross-ways, and squares. The chariot (*ratha*) was an important piece of military equipment from the beginning of the Vedic age. The *Sulvasutra* of Apastamba gives the following dimensions of the chariot: axle, 104 *angulis* (finger-breadths); pole, 188 *ahgulis*; and yoke, 86 *angulis.* The driver of the chariot (*sarathi)* stood on the right while the warrior (*savyastha*) was positioned on the left, either standing or sitting. Mention of such words as *kulya* (canal) and *khanitrima apah* (water obtained by digging) in the *Rg-Veda* suggests that some kind of irrigation system which utilized well water was in existence. Water used to be raised by a wheel to which a strap with a pail attached to it was fastened.

1.1.5.4. Post-Vedic Period

For evidence of the engineering and technical skills of ancient Indians in the early post-Vedic period we have to depend largely on literary sources. We are told of high walls with watch towers, strong ramparts with buttresses, and gates. A number of towns and cities, called *janapadas,* of considerable importance had developed before the seventh century B.C. Noteworthy among them were Ayodhya, Varanasi, Campa, Kampilya, Kausambi, Mathura, Mithila, Rajagrha, Saketa, Sravasti, Ujjayini, and Vaisall. An example of' a stone wall around a hill fortress before the sixth century B.C. has been unearthed near Rajagrha-modern Rajgir. The superstructures of buildings during this period were all made of wood or brick. Reference may in this connection be made to the ruins of some other ancient cities like Taksasila and Sanci. Taksasila is mentioned as a flourishing city and centre of learning in Buddhist literature probably compiled at least in the fourth century B.C. Archaeological excavations at the Bhir Mound have revealed several layers, of which the latest and uppermost was quite clearly of the late third or early second century B.C. The ruins unearthed in the Bhir Mound bear adequate testimony to the kind of house-building technique in vogue at the time. The buildings were of rubble masonry, in which kanjur and limestone, finished with a coaling of mud-plaster, were used. The remains of a fairly large house, with a courtyard and pillared hall and flanked by narrow, blind alleys have also been excavated in the western part of the Bhir Mound.

City life became more and more organized and by the time of Chandragupta Maurya (c. 324-300 B.C) it had taken a clear shape. There is evidence of the use of wooden piles in preparing the foundations of houses in soft soil during the pre-Maurya period. And wood continued to be an important constituent of house-building during the days of Chandragupta. The testimony of contemporary Greek historians shows that a wooden palisade was erected at this time for the fortification of Magadha's capital Pataliputra against floods. Other types of fortification were also known. Kautilya's *Arthasastra* affords a glimpse of Indian approach to town planning about this time. Kautilya's view of an ideal city is more or less in harmony with the description of Pataliputra given by Megasthenes and other Greek writers. The *Arthasastra* devotes one of its chapters to fortifications. Elaborate discussion follows in the next chapter about the construction of royal buildings and houses for different categories of citizens. Roads of various dimensions are prescribed for different purposes. According to Kautilya, the *durga* or fortified city is one of the seven constituent elements of the state. The meticulous way in which he deals with the lay-out and organization of forts gives the impression that the science ol fortified city-building had already advanced considerably.

The celebrated Chinese pilgrim Fa Hsien who visited Magadha during the reign of Chandragupta II (A.D 380-413) was struck with wonder at the sight of the royal palace of Asoka (c. 1269-232 B.C.) as also the houses set up by him for dispensing charity and medicine. Fa Hsien is on record as having noted that the palace of Asoka was not a work of men, but of spirits which piled up the stones, reared the walls and gates, and executed the elegant carving and inlaid sculpture-work in a way which no human hand of this world could accomplish'. Mention may be made in this connection of the ruins of a hundred-pillared hall discovered by excavations around the site of Mauryan edifices. One of the important innovations of Asoka was the substitution of stone for wood and brick. Structures and monuments of various types were set up in the country during his reign. The Mauryas introduced rock cut architecture and the practice of highly polishing the surface of sandstone pillars. The high polish, besides lending splendour, also tendered the surface water-repellant and resistant to actions of weather.

***1.1.5.5.* Buddhist Stupa and Viharas**

In the construction of religious edifices like *Stupas* and *Caitya-grhas* the Buddhists showed their engineering skill. Construction of *stupas* and *chaityas* was an important aspect of Buddhist religious life. The word *stupa* is derived from the root *stup*, meaning 'to heap', and suggests the mound shape and method of construction of these edifices, while the word *caitya* is derived from *citi* (altar). *Stupas* are pre-Buddhist in origin, being associated with burial mounds. The earliest Buddhist *stupas* were most probably low mounds consisting of layers of piled-up earthen tumulus which were separated from each other by thinner layers of stone chips and cloddy clay. The proportions of *stupas* after construction were enlarged in some cases, and a *stupa* is sometimes seen to have been enlarged several times. For this reason, and because of wreckage and decay, it is not always possible to determine the exact shape and type of construction of the original *stupa.* The earliest ones were built solid without any interior structural support or fill. Of the earliest dated *stupas*, those erected by Asoka were made of bricks and mud mortar. The Sunga period saw some innovations in construction like providing a veneer of hammer-dressed stones and in plastering the surface of the dome. Gradually the advantage of filling the core with rubble or other material was recognized. And the outward thrust of the fill material on the facing wall was minimized by dividing the inner space into compartments in the form of boxes or radiating spokes like those of the wheel of a cart. The stone railings and gates of *stupas* at Barhut and Sanchi clearly point to the earlier prototypes being made of wood.

The growth of Buddhism also inspired the establishment of monasteries *(viharas).* The earliest monasteries were probably simple dwellings made of wood, rubble and mud, or other perishable materials. Thus the *vihara* had a humble beginning with a building having a series of cell-like rooms, set around lacing an open space. The early Buddhist cave monasteries were quadrangular in shape, a typical example of which has been found at Nasik. This comprises a hall about 4.2 metres square with two cells in each of the three sides. The basic pattern for such *viharas* must have been evolved by the second century B.C. as seen from some of the specimens at Ajanta. The *vihara* had later a covered *mandapa* (courtyard) in the centre and with the installation of Buddha's image inside the cell in the back wall it became a *chaitya*-cum *Vihara,* serving the purpose of a shrine as well. At Nagarjunjakonda separate *chaitya* halls were provided in the *vihara* enclosures. The *viharas* gradually became larger, some of them being double-storeyed.

The *stupa* structure in its more developed form included a circular passage and a railing around it with gates (*torana)* as seen at Sanchi. Those in the South did not have the *toranas* but often had projected platforms (*ayaka)* at the cardinal points on which rested a row of tall cylindrical monolith pillars as at Jaggayyapeta, Amaravati, etc. The railings of the Amaravati *stupa* are made of marble and the dome also is covered with slabs of the same material. The *stupa*, a solid hemispherical dome (*anda*), usually was placed on one or tiered bases and surmounted by a railed pavilion (*harmika*). Later specimens show more ornate forms, the base-terraces as also the umbrellas being multiplied as at Nalanda (Bihar), Ratnagiri (Odisha), and other places. The outer surface of the basal cylinder (*medhi*) in southern examples, however, received encasing slabs sculptured tastefully as at Amaravati, Nagarjunakonda, etc. Another type of Buddhist structure was the *chaitya-grha*, a *stupa*-cum-sanctuary. Initially, the *stupa* was the object of worship. Later, an image of Buddha was either placed on it as at Ajanta and Ellora, or worshipped singly as at Nagarjunakonda. The *chaitya-grha* usually had an apsidal ground plan with the *stupa* in the apsidal end and a central nave separated from the side aisles by a row of pillars. Unfortunately no structural *chaitya-grha* survives, but the rock-cut examples depict them with gabled wooden roofs, initially simple in form, and with wooden pillars arranged with an inward rake to counter the outward thrust of the gabled roof.

The design of a rock-cut *chaitya-grha* or *vihara* was first planned by an architect or master craftsman. In choosing a suitable site he had to take into account such factors as the type of rock and whether it was free of faults, the existence of a suitable ledge from where the cave excavation could be started, and the proximity of spring or river water for drinking and bathing. The actual work must have been preceded by a detailed plan, it was necessary to know the exact position and size of stone blocks to be left standing which would later be carved into the desired shapes. For this precise measurements were necessary. Sketch-books containing patterns of the decorative stone carvings were no doubt essential. Some examples of unfinished caves show that the procedure was to excavate them from the ceiling downwards, thereby minimizing the need for scaffolding. As the rough cutting was being done inside the cave, simultaneously the decorative finish of the cave face would be in progress. This is borne out by some examples of caves which were abandoned before final excavation of the interior, although the face had been completed. Scaffolding was used for carving the capitals on the pillars.

1.1.5.6. Temple Architecture

The Gupta period *(*A.D.300-600) saw the beginnings of systematic construction on the basis of structural principles in temple architecture. The basic elements are a square sanctum *(garbhagrha)* for the image, a small pillared portico *(mukhamandapa*), and sometimes a covered circumambulatory passage *(pradahinapatha)* around the sanctum. The characteristic of the early temples is a flat roof as found at Sanchi, Tigawa, and Eran (all in Madhya Pradesh); later temples such as are seen at Deogarh (Madhya Pradesh) and Bhitargaon (Uttar Pradesh) show a rudimentary spire *(Sikhara).* There was a tendency during this period in stone construction to use stones larger than what the size of the building warranted. This was because the relationship between the strength and stability of construction and the economy of materials was yet to be understood. The stone was usually prepared at the site of the quarry. Fragments of carvings found at some quarries suggest that the sculpturing of the stones was also usually done at the quarry site, although sometimes this was done after the stone had been set in its place on the temple itself. All of this entailed accurate measurements.

Models to scale were perhaps sometimes employed. From about the fifth century A.D. brick-built religious structures, both Buddhist and Brahmanical, gradually became common in the alluvial plains. These include Buddhist *chaitya* halls, monasteries, and *stupas* as well as Brahmanical temples. Bricks were easy to procure in the plains, whereas stone was not always readily available. And bricks also afforded the advantage of convenient handling and flexibility in construction technique because of their small size. One difficulty encountered in the use of bricks was the bridging of spaces as in the case of doorways, windows, and other openings. The craftsmen attempted to overcome this problem by using exceptionally large bricks, some early examples being more than 50 cm. long. But even this was not always sufficient to surmount the difficulty, and so lintels of wood were resorted to. Stone lintels were subsequently found to be preferable to wooden ones. At one period brick structures with stone dressings became a rather common type of construction. Another method of spanning a gap was to over sail the courses of brick until they met. The vaulted roofs of *chaityas* were constructed in this manner, a thick coating of plaster being applied over the surface to create the curvilinear shape of a vault.

The post-Gupta period witnessed brisk building activity with experiments in various temple forms. Interesting results of such experimentations are seen at the principal centers at Aihole, Badami, Mahakuteswar, Pattadakal, and Alampur. At Aihole the Lad-Khan Visnu temple (sixth century), Meguti

Jaina temple (seventh century), and Kontgudi Siva temple (seventh century) typify the *mandapa* style with the shrine against the back wall of the pillared hall called *mandapa*; its sloping roof in three tiers has a *sikhara* in the centre and is supported by pillars of receding heights. The Durga temple (eighth century), though its roof is constructed on the same principle, has an apsidal plan in imitation of the Buddhist *chaitya-grha*. Similar structures are also to be found at Chejarla and Ter. Subsequent development is observed in the later examples in which components of the sanctum have a northern *Sikhara*, a pillared hall carrying a flat roof, and a porch. This is exemplified by the Huccimalligudi temple and others, sometimes with a little adjustment of the *Sikhara* in both plan and design. Such specimens are found at Alampur (eighth century), Pattadakal (eighth century), Osian (ninth century), Roda (ninth century), Jageswar (ninth-tenth century), etc.

The South Indian temples of the *vimana* (lit. well-proportioned) type with a pyramidal *Sikhara* made their earliest appearance at Badami in the simple form of the temple known as Malegitu-Sivalaya (garland maker's temple). Later variants and developed forms of *vimana* with *Mas* (miniature oblong shrine with barrel-vault roof), *karna-kutas* (miniature square shrine at the corner of the roof), and *nasikas* (arched opening above the superstructure wall, projecting from the facade) are seen on the Virupaksa temple (eighth century) at Pattadakal, Shore temple (eighth century) at Mahabalipuram, Kailasanatha temple (eighth century) at Kanchipuram, Brhadisvara temple (tenth century) at Tanjore, Airavatesvara temple (twelfth century) at Darasuram, etc. Equally interesting are the Hoysala (twelfth-thirteenth century) temples at Halebid and Belur, famous for their intricately carved sculptured decorations, a kind of which is also seen in some of the Vijayanagara (fourteenth century) temples noted for large-sized *mandapas.* Gateways *(gopuram)* to the temple enclosures constituted another important feature. These were usually capped by a vaulted roof, the later examples soaring high, the oblong size at each storey diminishing with the height. Although there are many examples, the temple-city at Srirangam has tall *gopuram* fixed in the seven concentric enclosure walls around the temple of Ranganathasvami (Visnu) which is unique.

The vaulted roof was widely distributed and appeared on structural temples in North India from the eighth century. The Vaital-Deul (eighth century) at Bhubaneswar, the Teli-ka-Mandir (ninth century) at Gwalior, and Nava-Durga temple (ninth century) at Jageswar are examples of this type. Though essentially linear in elevation, the North Indian *Sikharas* have some variations. While at Bhubaneswar itself the typical Odishan form is represented by the Muktesvara temples (tenth century), the Rajarani temple (eleventh century) shows an interesting experiment with miniature *Sikharas* clustered around the *jangha* (bottom portion of the spire) as in the temples of western and central India including those at Khajuraho. The Lingaraja temple (eleventh century) shows the culmination and grandeur of this type of temple, but the Surya temple (thirteenth century) at Konarak (Puri district) in its original form with bold and lively sculptural decorations must have been a magnificent work.

At Khajuraho, again, a beginning was made with a plain *Sikhara* without any embellishment of the miniature spires (*uru-srngas)* which became the characteristics of the later examples. The temple components were *ardha-mandapa* (entrance porch), *mandapa* (hall), *antarala* (vestibule), and *garbhagrha* (sanctum), the entire structure being placed on a high platform and the walls decorated with beautiful carvings. The result of these experiments was the emergence of two broad temple architectural styles, one predominating in the North called *nagara* and the other common in the South called *dravida* or *vimana.* The main structural component during the post-Gupta period continued to be stone. One wonders how the big slabs of stone used in the temple structures were transported and set up in position to make the temples. From reliefs carved on temples and from a manuscript describing the building operations of the temple at Konarak one gets an idea of the methods employed in transporting large stones to the construction site and hoisting them into place. They were transported on barges along rivers and streams or pulled by elephants over wooden rollers. They were lifted into place by means of rope pulleys on scaffolding. Ramps of timber or sand were built on which to haul up exceptionally large stone slabs.

The Jaina temples did not have any distinct form of architecture. In later days the Jains built up a large number of temples in a rather unplanned manner at the sacred hills like Girnar (Junagarh district) and

Satrunjaya (Bhavnagar district). Nonetheless, the Dilwara temple at Mount Abu and the temple of Neminatha do evoke appreciation, the former especially for its intricately carved sculptures. The later temples of Bengal are characterized by a simple curved roof, imitating the bamboo-and-thatch constructions of the region. The Vishnupur (Bankura district) temples belong to this type. There are still other popular types of miniature shrines grouped in tiers to form five- or nine-spired (*panca*o r *nava-ratna)* shrines.

The temple architecture including *Nagara, Dravida, Besara* and *Kalingan* (within Nagara) have their separate treaties on architecture. Treaties such as Silpratnakosa, Silpapradipa, Silpasastra, Bhubanapradipa, Mayamatam, Visnudharmottara Purana, Silpasarani etc are codified by *Silpin*, these book throw ample light on the ancient Indian architecture and archeometry.

1.1.5.7. Rock-Cut Architecture

The rock-cut temples, both cut in and out of the rock, mostly followed the contemporary architectural styles. The earliest group of such temples excavated by Asoka in the Barabar and Nagarjuni hills (Gaya district), depicts the basic forms of rock-cut architecture. Subsequent rock-cut shrines, especially those of the Buddhists in western India at Bhaja Kondhane, Pitalkhora, Ajanta, Junar Karle, and Junagarh, were fashioned in imitation of the earlier wooden constructions. Among the monasteries, the two double storeyed ones at Ellora are the largest. Brahmanical caves are at their best at Badami, Ellora, Elephanta, and Mahabalipuram with a profusion of beautifully carved-out sculptures. At Mahabalipuram huge granite boulders have been chiseled to various shapes.

The Kailasa temple at Ellora (A.D.800) stands unparalleled as a monument to the artistry and craftsmanship of Indian rock-cut architecture. The temple of Kailasa was executed by cutting away more than fifty million tonnes of rock from the sloping hill by means of hammer and chisel, a process which took some 100 years. The first step was to cut three trenches at right angles into the hill, thereby isolating a massive block of stone over 60 m. long, 30 m. wide, and 30 m. high. Next, this block was carved from the top downwards and hollowed out into the form of the temple with its intricate carvings. In order to highlight the shape of the temple against the grey stone of the mountain surrounding it, the entire edifice was coated with a white gesso, imparting to it a brilliant sheen. The Jains too carved out retreats in the hills of Udayagiri and Khandagiri near Bhubaneswar in the first century B.C. and shrines later at Ellora, Badami, and elsewhere.

1.1.6. Conclusion

India has consistently been a scientific country, since the start of civilization. Vedic Hindus evinced special interest in two particular branches of mathematics, viz. geometry and astronomy. Sacrifice was their prime religious avocation. Each sacrifice had to be performed on an altar of prescribed size and shape. They were very strict regarding this and thought that even a slight irregularity in the form and size of the altar would nullify the object of the whole ritual and might even lead to an adverse effect. So the greatest care was taken to have the right shape and size of the sacrificial altar. Thus originated problems of geometry and consequently the science of geometry. The study of astronomy began and developed chiefly out of the necessity for fixing the proper time for the sacrifice. This origin of the sciences as an aid to religion is not at all unnatural, for it is generally found that the interest of a people in a particular branch of knowledge, in all dimes and times, has been aroused and guided by specific reasons. In the case of the Vedic Hindu that specific reason was religious. The term *ganita*, meaning the science of calculation, also occurs copiously in Vedic literature. The *Vedanga Jyotisa* gives it the highest place of honour amongst all the sciences which form the Vedanga. In India, a substantial part of mathematics developed as a sequel to astronomical advancement. Scientist such as Aryabhata I (A.D 476), Brahmagupta, Varahmihira, Apastamba, Baudhayana, Katyayana, Manava, and a few others flourished during ancient time in India. Ayurveda, the traditional system of Indian medicine, is a special branch of knowledge on life dealing with both body and mind. **T**he achievements of Indian people in the field of engineering began in the proto-historic times, from the third millennium B.C. or even earlier. All forms of civil engineering from drainage systm to huge temple both rock cut and structural are conceived and build by ancient India, allthose still extant shows the engineering skill of our ancestors.

1.1.7. Summary

- *The work of the Indian National Science Academy and other learned bodies, the development of sciences in India during the ancient period has draw that India has consistently been a scientific country, right from Vedic to modern times.*
- *Vedic Hindus evinced special interest in two particular branches of mathematics, viz. geometry and astronomy. Sacrifice was their prime religious avocation so the greatest care was taken to have the right shape and size of the sacrificial altar. Thus originated problems of geometry and consequently the science of geometry.*
- *The study of astronomy began and developed chiefly out of the necessity for fixing the proper time for the sacrifice.*
- *The term ganita, meaning the science of calculation, also occurs copiously in Vedic literature. The Vedanga Jyotisa gives it the highest place of honour amongst all the sciences which form the Vedanga.*
- ***T**he development of a certain level of mathematical knowledge dictated by the material needs of a society is a common phenomenon of all civilizations. In India, a substantial part of mathematics developed as a sequel to astronomical advancement.*
- *Mathematicians and orientalists are generally agreed that the system with zero originated in India and thence travelled to other parts of the world and the word-numerals and their use in a decimal place-value arrangement represent another unique development in India.*
- *Much progress seems, however, to have been made in the Brahmana period when astronomy came to be regarded as a separate science called naksatra-vidya (the science of stars). An astronomer was called a naksatra-daria (star-observer) or ganaka (calculator).*
- *Scientific Indian astronomy dates from the year A.D 499 when Aryabhata I of Kusumapura (Pataliputra or Patna) began to teach astronomy to his pupils. Brahmagupta, Varahmihira, Bhaskara etc also contributed to the growth of astronomy in ancient India.*
- *Concepts of scientific astronomy in India were not borrowed wholesale from cither Babylonian or Greek science rather the ancient sutrakaras or writers of aphorisms who stated only their results but not the methods by which they obtained them.*
- *Ayurveda, the traditional system of Indian medicine, is a special branch of knowledge on life dealing with both body and mind. This is implicit in the two components of the term ayurveda: dyus and veda. The former means 'life', and the latter, 'knowledge' or more precisely 'science'.*
- *The scope of Ayurveda is not limited to physical health alone. It also seeks to promote a totality of physical, mental, and spiritual health in the context of man's interaction with his environment.*
- ***T**he achievements of Indian people in the field of engineering began in the proto-historic times, from the third millennium B.C. during Harappan period.*
- *A number of towns and cities, called janapadas, of considerable importance had developed before the seventh century B.C. Noteworthy among them were Ayodhya, Varanasi, Campa, Kampilya, Kausambi, Mathura, Mithila, Rajagrha, Saketa, Sravasti, Ujjayini, and Vaisall.*
- *In the construction of religious edifices like Stupas and Caitya-grhas the Buddhists showed their engineering skill.*
- *The growth of Buddhism also inspired the establishment of monasteries (viharas). The design of a rock-cut chaitya-grha or vihara was first planned by an architect or master craftsman.*
- *The Gupta period (A.D.300-600) saw the beginnings of systematic construction on the basis of structural principles in temple architecture.*

- *The rock-cut temples, excavated by Asoka in the Barabar and Nagarjuni hills (Gaya district), depicts the basic forms of rock-cut architecture. The Kailasa temple at Ellora (A.D.800) stands unparalleled as a monument to the artistry and craftsmanship of Indian rock-cut architecture.*

1.1.8. Exercise

- Give an account of the ancient Indian astronomy.
- What are the theories given by Aryabhatta in the field of astronomical science?
- Discuss the mathematical knowledge of Indian in the ancient period.
- Write an essay on Ancient Indian Medical Science.
- Discuss the architectural style flourished in ancient India.

1.1.9. Further Readings

- Acharya , P. K ., Dictionary o f Hindu Architecture. London, 1927.
- Bose , D. M ., Sen , S. N., and Subba rayappa , B. V. (Eds.), A Concise History o f Science in India. Indian National Science Academy, New Delhi, 1971.
- Chatterji, Sunm Kumar (E d.), The Cultural Heritage o f India. Vol. V. The Ramakrishna Mission Institute of Culture, Calcutta, 1978.
- Chattopadhyaya , Debiprasad (Ed.), Studies in the History o f Science in India (2 Vols.). Editorial Enterprises, New Delhi, 1982.
- Dampier, W. C., History of Science and its Relations with Philosophy and Religion. 4th Edn. Cam bridge, 1961.
- Forbes , George , History o f Astronomy. Watts & Co., London, 1909.
- Forbes , R . J ., Metallurgy in Antiquity. Leyden, 1950.
- Haldane , J . B. S., Science and Indian Culture. New Age Publishers Pvt. L td., Calcutta, 1965.
- Frawley, D., Planets in the Vedic literature, Indian Journal of History of Science. 29.495-506, 1994.
- B Datta and A N Singh, History of Hindu Mathematics: A source book, Parts 1 and 2 (single volume), Asia Publishing House, Bombay, 1962.
- George G Joseph, Crest of the Peacock, Non-European roots of mathematics, Third edition, Princeton University Press, Princeton, NJ, 2011.

*****

UNIT-I

Chapter-II

DEVELOPMENTS IN METALLURGY

Use of Copper, Bronze and Iron in Ancient India

Structure

1.2.0. Objectives

In this lesson, students investigate the historical development of metallurgy in ancient India.. After studying this lesson you will be able to:

- *understand the origin, consequences and significance of metallurgy in ancient India;*
- *discuss the origin and development of copper, gold, Iron and other metal in ancient India;*
- *investigate the textual references of metallurgy in ancient India and*
- *Identify the socio-economical significance of metallurgy in ancient India.*

1.2.1. Introduction

Technology is today defined as applied science, but early humans developed technologies such as stone-working, agriculture, animal husbandry, pottery, metallurgy, textile manufacture, bead-making, wood-carving, cart-making, boat-making and sailing-with hardly any science to back them up. If we define technology as a human way of altering the surrounding world for making life easier, we find that the first stone tools in the Indian subcontinent go back more than two million years! Jumping across ages, the 'Neolithic revolution' of some 10,000 years ago saw the development in agriculture in parts of the Indus and the Ganges valleys, which in turn triggered the need for pots, water management, metal tools, transport, etc. Metallurgy brought about important changes in human society, as it gave rise to a whole new range of weapons, tools and implements. Some of these had been made in stone earlier, it is true, but the result was coarser as well as heavier. Metal, precious or not, is also a prime material for ornaments, and thus enriches cultural life. Metallurgy may be defined as the extraction, purification, alloying and application of metals. Today, some eighty-six metals are known, but most of them were discovered in the last two centuries. The 'seven metals of antiquity', as they are sometimes called, were, more or less in order of discovery: gold, copper, silver, lead, tin, iron and mercury. For over 7,000 years, India has had a high tradition of metallurgical skills; let us see some of its landmarks.

1.2.2. Copper Metallurgy in Ancient India

1.2.2.1. Harappan Civilization:

The first evidence of metal in the Indian subcontinent comes from Mehrgarh in Baluchistan, where a small copper bead was dated to about 6000 BCE; it is however thought to have been native copper, not the smelted metal extracted from ore. The growth of copper metallurgy had to wait for another 1,500 years; that was the time when village communities were developing trade networks and technologies which would allow them, centuries later, to create the Harappan cities. Archaeological excavations have shown that Harappan metal smiths obtained copper ore from the Aravalli hills, Baluchistan or beyond. They soon discovered that adding tin to copper produced bronze, a metal harder than copper yet easier to cast, and also more resistant to corrosion. Whether deliberately added or already present in the ore, various 'impurities' such as nickel, arsenic or lead enabled the Harappans to harden bronze further, to the point where bronze chisels could be used to dress stones. Shaping copper or bronze involved techniques of fabrication such as forging, sinking, raising, cold work, annealing, riveting, lapping and joining.

Among the metal artifacts produced by the Harappans, objects discovered are spearheads, arrowheads, axes, chisels, sickles, blades (for knives as well as razors), needles, hooks, and vessels such as jars, pots and pans, besides objects of toiletry such as bronze mirrors; those were slightly oval, with their face raised, and one side was highly polished. The Harappan craftsmen also invented the true saw, with teeth and the adjoining part of the blade set alternatively from side to side, a type of saw unknown elsewhere until Roman times. Besides, many bronze figurines or humans such as the well-known 'Dancing Girl', for instance and animals like rams, deer, bulls etc. have been unearthed from Harappan sites. Those figurines were cast by the lost-wax process: the initial model was made of wax, then thickly coated with clay; once fired which caused the wax to melt away or be 'lost', the clay hardened into a mould, into which molten bronze was later poured. Harappans also used gold and silver to produce a wide variety of ornaments such as pendants, bangles, beads, rings or necklace parts, which were usually found hidden away in hoards such as ceramic or bronze pots. While gold was probably panned from the Indus waters, silver was perhaps extracted from galena, or native lead sulphide.

1.2.2.2. Beyond the Harappans:

In the later phase of Harappan culture, a 'Copper Hoard' culture of still unclear authorship produced massive quantities of copper tools are underway central and northern India. Later, in the classical age, copper-bronze smiths supplied countless pieces of art. Let us mention the huge bronze statue of the Buddha made between 500 and 700 CE in Sultanganj in Bihar, measuring 2.3 m high, 1 m wide, and weighing over 500 kg, it was made by the same lost-wax technique that Harappans used three millenniums earlier. So were thousands of statues made later in Tamil Nadu, such as the beautiful Nataraja statues of the Chola period, among other famous bronzes. Of course, all kinds of bronze objects of daily use have continued to be produced; for instance, highly polished bronze mirrors are still made in Kerala today, just as they were in Harappan times.

1.2.3. Gold Metallurgy

The noble metals, gold and silver, are found in the native state, and as is well known, gold and silver were used to make jewelry and sheet metal due to the great ductility and lustre of the pure metals. Some of the early rich finds of gold artifacts were from the cemeteries in Bulgaria in Europe (5th millennium BC) with accouterments of hammered and sheet gold. Some of the most elegant gold vessels made by the repousse technique come from the Mesopotamia (ca 2500 BC). Spectacular gold castings are known from ancient Pharaohnic Egypt, such as the enigmatic face of the young Pharaoh Tutenkhamen (ca 1300 BC). Early gold and silver ornaments from the Indian subcontinent are found from Indus Valley sites such as Mohenjodaro (ca 3000 BC). These are on display in the National Museum, New Delhi.

In antiquity gold would usually have been collected by panning alluvial sands from placer deposits. However India has the distinction that the deepest ancient mines in the world for gold come from the Maski region of Karnataka with carbon dates from the mid 1st millennium BC. A rather delightful piece of conjecture is that tales of Herodotus, the Greek, about 'gold-digging ants' from India refers to marmot, a type of rodent found in Afghanistan, who dig up the river sand which could then have been panned for gold by the inhabitants.

Surface tension was used to turn melted gold filings into spheres. The granulation technique was also used to make gold jewelry in India in the late 1st millennium BC to early Christian era. Interestingly, as far as silver production goes, the Aravalli region in north-west India along with Laurion in Greece and the Roman mines of Rio Tinto in Spain ranks amongst the few major ancient silver producing sites from about the mid 1st millennium BC onwards.

1.2.4. Iron Metallurgy in ancient India

While the Indus civilization belonged to the Bronze Age, its successor, the Ganges civilization, which emerged in the first millennium BCE, belonged to the Iron Age. But recent excavations in central parts of the Ganges valley and in the eastern Vindhya hills have shown that iron was produced there possibly as early as in 1800 BCE. Its use appears to have become widespread from about 1000 BCE, and we find in late Vedic texts mentions of a 'dark metal' (krṣṇāyas), while earliest texts (such as the Rig-Veda) only spoke of *ayas*, which, it is now accepted, referred to copper or bronze. Whether other parts of India learned iron technology from the Gangetic region or came up with it independently is not easy to figure out. What seems clear, however, is that the beginnings of copper-bronze and iron technologies in India correspond broadly with those in Asia Minor (modern Turkey) and the Caucasus, but were an independent development, not an import.

1.2.4.1. Wootz Steel

Instead, India was a major innovator in the field, producing two highly advanced types of iron. The first, wootz steel, produced in south India from about 300 BCE, was iron carburized under controlled conditions. Exported from the Deccan all the way to Syria, it was shaped there into 'Damascus swords' renowned for their sharpness and toughness. But it is likely that the term 'Damascus' derived not from

Syria's capital city, but from the 'damask' or wavy pattern characteristic of the surface of those swords. In any case, this Indian steel was called 'the wonder material of the Orient'. A Roman historian, Quintius Curtius, recorded that among the gifts which Alexander the Great received from Porus of Taxila (in 326 BCE), there was some two-and-a-half tons of wootz steel-it was evidently more highly prized than gold or jewels. Later, the Arabs fashioned it into swords and other weapons, and during the Crusades, Europeans were overawed by the superior Damascus swords. It remained a favoured metal for weapons through the Moghul era, when wootz swords, knives and armours were artistically embellished with carvings and inlays of brass, silver and gold.

Wootz steel is primarily iron containing a high proportion of carbon (1.0-1.9%). Thus the term wootz applies to a high-carbon alloy produced by crucible process. The basic process consisted in first preparing sponge iron; it was then hammered while hot to expel slag, broken up, then sealed with wood chips or charcoal in closed crucibles that were heated, causing the iron to absorb appreciable amounts of carbon; the crucibles were then cooled, with solidified ingot of wootz steel remaining.

Right from the 17th century, several European travellers documented India's iron and steel-making furnaces. From the 18th century, savants in England, France and Italy tried to master the secrets of wootz; the French Jean-Robert Bréant, conducting over 300 experiments by adding various metals to steel, understood the role of the high carbon proportion in wootz, and was the first European who successfully produced steel blades comparable to the Indian ones. Together, such researches contributed to the understanding of the role of carbon in steel and to new techniques in steel-making.

The second advanced iron is the one used in the famous 1,600-year-old Delhi Iron Pillar, which, at a height of 7.67 m, consists of about six tons of wrought iron. It was initially erected 'by Chandra as a standard of Vishnu at Vishnupadagiri', according to a six-line Sanskrit inscription on its surface. 'Vishnupadagiri' has been identified with modern Udayagiri near Sanchi in Madhya Pradesh, and 'Chandra' with the Gupta emperor, Chandragupta II Vikramaditya (375-414 CE). In 1233, the pillar was brought to its current location in the New Delhi's Qutub complex, where millions continue to come and see this 'rustless wonder'.

But why is it rustless, or, more precisely, rust-resistant is still a major question. Here again, numerous experts, both Indian and Western, tried to grasp the secret of the pillar's manufacture. Only recently have its rust-resistant properties been fully explained. They are chiefly due to the presence of phosphorus in the iron: this element, together with iron and oxygen from the air, contributes to the formation of a thin protective passive coating on the surface, which gets reconstituted if damaged by scratching. It goes to the credit of Indian blacksmiths that through patient trial and error they were able to select the right type of iron ore and process it in the right way for such monumental pillars.

There are a few more such pillars in India, for instance at Dhar (Madhya Pradesh) and Kodachadri Hill (coastal Karnataka). Besides, the same technology was used to manufacture huge iron beams used in some temples of Odisha, such as Jagannath of Puri (12th century). The iron beams at Konarak's famous sun temple are of even larger dimensions. Chemical analysis of one of the beams confirmed that it was wrought iron of a phosphoric nature (99.64% Fe, 0.15% P, traces of C, traces of S and no manganese).

1.2.5. Zinc

The earliest firm evidence for the production of metallic zinc is from India. Of the metals used in antiquity zinc is one of the most difficult to smelt since zinc volatalises at about the same temperature of around 1000oC that is needed to smelt zinc ore. Indian metallurgists were familiarity with zinc deserves a special mention because, having a low boiling point (907°C), it tends to vaporize while its ore is smelted. Zinc, a silvery-white metal, is precious in combination with copper, resulting in brass of superior quality. Sometimes part of copper ore, pure zinc could be produced only after a sophisticated 'downward' distillation technique in which the vapour was captured and condensed in a lower container. This technique, which was also applied to mercury, is described in Sanskrit texts such as the 14th-century Rasaratnasamuccaya.

There is archaeological evidence of zinc production at Rajasthan's mines at Zawar from the 6th or 5th century BCE. The technique must have been refined further over the centuries. India was, in any case, the first country to master zinc distillation, and it is estimated that between 50,000 and 100,000 tons of zinc was smelted at Zawar from the 13th to the 18th century CE! British chroniclers record continuing production there as late as in 1760; indeed, there is documentary evidence to show that an Englishman learned the technique of downward distillation there in the 17th century and took it to England-a case of technology transfer which parallels that of wootz steel. Another remarkable artistic innovation by Indian metalworkers of the past was the use of zinc in making highly elegant bidri ware, an inlayed zinc alloy, which came into vogue under the Muslim rulers of the Bidar province in the Hyderabad region from about the 14th century. AD.

1.2.6. Social Context of Metallurgy in Ancient India

We should finally note that most of India's metal production was controlled by specific social groups, including so-called tribes, most of them from the lower rungs of Indian society. For instance, the Agarias of Uttar Pradesh and Madhya Pradesh are reputed iron smiths, and there are still such communities scattered across Jharkhand, Bihar, West-Bengal, Kerala and Tamil Nadu. Together, they contributed substantially to India's wealth, since India was for a long time a major exporter of iron. In the late 1600s, shipments of tens of thousands of wootz ingots would leave the Coromandel Coast for Persia every year. India's iron and steel industry was intensive till the 18th century and declined only when the British started selling their own products in India while imposing high duties on Indian products. Industrially produced iron and steel unavoidably put a final stop to most of India's traditional production.

1.2.7. Textual reference on ancient Indian Metallurgy

Note: Many texts of chemistry refer to the working of metals, especially precious ones (a few extracts are below), but it should be kept in mind that some of India's greatest metallurgical advances-such as wootz steel or rust-resistant iron-do not figure in any known texts; they were the work of communities of craftsmen who perfected such practices from generation to generation, but did not generally leave written testimonies behind.

1.2.7.1. Rig-Veda:

There are many more references in the Vedas to metal and metal-working, often used as a metaphor. The word for metal was *ayas*, which in the Rig-Veda, refers to copper or bronze, not to iron. In later literature, terms like *krsnayas, kalayasa or syamayas*, i.e., 'dark metal', came into use, which clearly referred to iron; loha (literally, 'red') or lohāyas initially referred to copper, but later became a generic term for metal, and often came to mean iron.

1.2.7.2. Arthasastra:

Kautilya's famous treatise of governance and administration, the Arthasastra, dates back to Mauryan times, a 4^{th} centuries BCE. A passage, from a long chapter on the 'department of mines', reveals an intimate knowledge of the different types of metal ores and the ways to test and purify different metals, or to create alloys. Kautilya said, that the Director of Mines, being conversant with the sciences of metal veins in the earth and metallurgy, the art of smelting and the art of colouring gems, or having the assistance of experts in these, and fully equipped with workmen skilled in the work and with implements, should inspect an old mine by the marks of dross, crucibles, coal and ashes, or a new mine, where there are ores in the earth, in rocks or in liquid form, with excessive colour and heaviness and with a strong smell and taste.

1.2.7.3. **Varahamihira** (5th CE):

In Khaḍgalakṣaṇam, Varahamihira explains the process of carburization and hardening of iron swords. Carburization is the controlled addition of carbon to iron, so as to turn it into steel; it is usually done by adding organic substances, whether vegetal or animal, in the course of the smelting.

1.2.7.4. **Nagarjuna** (7th or 8th century CE):

Narjuna, in his, Rasendramaṅgalam, a process for whitening copper is described. It would be interesting to try and put such recipes to test so as to assess their value.

1.2.7.5. Vagbhata

Vagbhaṭa **(**13th century), in his Rasaratnasamuccaya gives us a systematic exposition of the principal metals in a well-known text of alchemy. Each metal's properties and medicinal uses are clearly brought out, although, of course, within the alchemical framework of the times.

1.2.8. Classification of metals in Ancient Indian literature

Acoording to ancient Indian literary reference, in nature there are four suddha lohas (native metals) viz., suvarṇa (gold), rajata (silver), tamra (copper) and loha (iron). In addition there are two putilohas- naga (lead) and vaṅga (tin) and three misra loha (alloys) viz., pittala (brass), kaṃsya (bell metal) and varta loha (an alloy made of five metals). The term loha is derived from the root luh which means karsana.

1.2.9. Conclusions

The above discussion indicates that there is growing evidence to suggest that ancient Indian metallurgists have also made major contributions which deserve their place in the metallurgical history of the world along with other great civilizations of the world. As clearly seen in the case of zinc and high-carbon steel, ancient India contributed significantly to their modern metallurgical advances and in the development of metallurgical study leading to the Industrial Revolution in Europe.

1.2.10. Summary

- *The first evidence of metal in the Indian subcontinent comes from Mehrgarh in Baluchistan, where a small copper bead was dated to about 6000 BCE.*
- *Archaeological excavations have shown that Harappan were master craftsman and had knowledge on copper metallurgy. Even they manufactured bronze by mixing copper and tin.*
- *In the post Harappan culture, a 'Copper Hoard' culture of still unclear authorship produced massive quantities of copper tools are underway central and northern India. In the classical age, copper-bronze smiths supplied countless pieces of art.*
- *India has the distinction that the deepest ancient mines in the world for gold come from the Maski region of Karnataka with carbon dates from the mid 1st millennium BC.*
- *While the Indus civilization belonged to the Bronze Age, its successor, the Ganges civilization, which emerged in the first millennium BCE, belonged to the Iron Age.*
- *India was a major innovator in the field, producing two highly advanced types of iron. The first, wootz steel, produced in south India from about 300 BCE, was iron carburized under controlled conditions.*
- *Right from the 17th century, several European travellers documented India's iron and steel-making furnaces.*
- *The second advanced iron is the one used in the famous 1,600-year-old Delhi Iron Pillar, 'rustless wonder' which, at a height of 7.67 m, consists of about six tons of wrought iron.*
- *The earliest firm evidence for the production of metallic zinc is from India. Of the metals used in antiquity zinc is one of the most difficult to smelt since zinc volatalises at about the same temperature of around 1000oC that is needed to smelt zinc ore.*
- *There is archaeological evidence of zinc production at Rajasthan's mines at Zawar from the 6th or 5th century BCE.*
- *Most of India's metal production was controlled by specific social groups, including so-called tribes, most of them from the lower rungs of Indian society. For instance, the Agarias of Uttar Pradesh and Madhya Pradesh are reputed iron smiths, and there are still such communities scattered across Jharkhand, Bihar, West-Bengal, Kerala and Tamil Nadu. Together, they contributed substantially to India's wealth, since India was for a long time a major exporter of iron.*
- *Many texts of chemistry refer to the working of metals, especially precious ones. Some of them such as Kauṭilya's Arthasastra, Varahamihira' Khaḍgalakṣaṇam, Nagarjuna' Rasendramaṅgalam,*

Vagbhaṭa's Rasaratnasamuccaya etc gives us a systematic exposition of the principal metals in a well-known text of alchemy.

- *Acoording to ancient Indian literary reference, in nature there are four suddha lohas (native metals) viz., suvarṇa (gold), rajata (silver), tamra (copper) and loha (iron). In addition there are two putilohas- naga (lead) and vaṅga (tin) and three misra loha (alloys) viz., pittala (brass), kaṃsya (bell metal) and varta loha (an alloy made of five metals). The term loha is derived from the root luh which means karsana.*

1.2.11. Exercise

- Write a note on the tradition of copper metallurfy in Ancient India.
- Could the Harappans have developed their urban civilization without copper / bronze metallurgy? Justify your answer.
- Describe the various texts, wherein the basic literary references informs us about ancient Indian metallurgy.
- Why were most of India's metallurgical practices the prerogative of lower sections of the society, such as rural and tribal communities.
- Discuss the growth of Iron Metallurgy in Ancient India.

1.2.12. Further reading

- Agrawal, D. P. and Ghosh, A. (eds.)., The Copper- bronze Age in India. Munshiram Manoharlal, New Delhi, 1971.
- Agrawal, D.P., Ancient Metal Technology and Archaeology of South Asia (A Pan-Asian Perspective), Aryan Books International, New Delhi, 2000.
- Balasubramaniam, R., Marvels of Indian Iron through the Ages, Rupa & Infinity Foundation, New Delhi, 2008.
- Bhardwaj, H. C., Aspects of Ancient Indian Technology, Munshiram Manoharlal, New Delhi, 1979.
- Biswas, A. Kumar., Minerals and Metals in Ancient India, D.K. Printworld, New Delhi, 1996.
- Biswas, A.K., Biswas, S. and Chakraborty, N.A., Archaeo-material studies in India and Literary Evidences in Historical Archaeology of India, edited by A.Ray and S.Mukherjee, Books and Books, New Delhi, 1990.
- Biswas, Arun Kumar and Biswas, Sulekha; Minerals and Metals in Ancient India, 2 Volumes, U.K. Print world (P) Ltd, 1996.
- Lal, B.B., An Examination of some Metal Images from Nalanda, Anc. India, 12, 53-57,1956.
- Neogi.P., Copper in Ancient India, Janaki Prakashan,Patna, 1917.
- Shrivastava, R., Mining and Metallurgy in Ancient India, Munshiram Manoharlal, New Delhi, 2006.

*****

Unit-1
Chapter-III
DEVELOPMENT OF GEOGRAPHY
Geography in Ancient Indian Literature

Structure

1.3.0. Objectives

In this lesson, students investigate geographical knowledge of ancient Indian. After completing this chapter, you will be able:

- *to understand the geographical knowledge of Indian in a Vedic age;*
- *to evaluate the concept of Bharatvarsa and Jambudvipa in ancient Indian literature;*
- *To understand the concept of earth geography as conceived in the mind of ancient India as reflected in their literature and*
- *to review the other inferences on geography in ancient Indian literature;*

1.3.1. Introduction

Geography as a branch of scientific study has developed as a consequence of man's immediate need for functioning in the world around him. Familiarity with the surrounding terrain, its lakes and rivers, the climatic conditions, and the neighbouring tribes- matters of daily experience-was the rudimentary beginning of geographical study. In India the earliest references to geographical data are found in the *Rg-Veda.* Casual references to tribes, rivers, and other geographical landmarks indicate that geographical knowledge was not lacking during the Vedic period. The chapter will discuss the development of Geography in ancient India on the basis of references of found in ancient literature.

1.3.2. Vedic Period

The ancient Indians conceptions of the universe and the earth determined to a great extent their understanding of the earth's physical properties and conditions. In Vedic literature the universe is sometimes conceived as consisting of the earth and sky (heaven), and sometimes of the earth, air (atmosphere), and sky. Solar bodies are understood as belonging to the realm of the sky and atmospheric phenomena such as lightning to that of the air. The semispherical shape of the sky as seen by the eye led to the comparison in the *Rg-Veda* of the sky and earth to two great bowls (*camva*) turned towards each other. The *Satapatha Brahmana* uses the term *graha,* which later came to mean 'planet', but in this text the word seems to signify a sort of power. The question whether the Vedic Indian used the word to denote 'planet' is not free from doubt. Some scholars like Olden berg identify the *grahas* with the *adityas,* numbering seven -the sun, moon, and the five planets.

The earth is denoted in the *Rg-Veda* by such words as *prthivi* (the expansive or large), *prthvi* or *urvi* (the broad), *mahi* (the great), *apara* (the limitless), and *uttana* (the stretched out). The *Rg-Veda* contains references suggesting the spherical shape of the earth. It says, for instance, that every sacrificial altar or ground on the surface of the earth is its centre.

This has been interpreted as implying the earth's sphericity. Elsewhere the earth is compared to a wheel and the dawn is stated to precede the sunrise. In the *Satapatha Brahmana* the earth is expressly mentioned as being circular (*parimandala*). In the cosmogonic and theosophic hymns of the *Atharva-Veda* the earth and the heavens have been imagined as constituting two hemispheres. The Vedic Hindus had clear ideas about the four directions, further elaborated in connection with the placement of sacrificial altars.

The term *dvipa* (island) occurs in the *Rg-Veda* and other Vedic texts. But it is unlikely that the word refers to any island, continent, or major land area as it does in the Epics and Puranas. Sandbanks are perhaps indicated by the term. It appears likely that no major geographical divisions of the earth arc mentioned in Vedic literature. Use of the expression *sapta sindhavak*, i.e. 'seven rivers', however, has led some scholars to think that the Rg-Vedic Indians conceived of a definite territory covering the basin, of some of the existing rivers. The names of a large number of rivers occur in the *Rg-Veda*. Some among these are the Sindhu, Sarasvati, Satadru, Vitasta, Sarayu, and Gomati. The *Rg-Veda* also refers to mountains, e.g. the Himavant and Mujavant. The Himavant may reasonably be identified with the Himalayas, though it is possible that it included hills of the Suleiman range. The ancient lexicographer Yaska suggests that Mujavant is equivalent to Munjavant which figures in the *Mahabhdrata* as the name of a mountain in the Himalayan range. The *Kausitaki Upanisad* speaks of the Daksina-parvata, which is probably to be identified with the Vindhyan range. The names of many places also figure in Vedic texts. In the Vedic period a kind of zonal geographical conception evolved.

The *Satapatha Brahmana* calls the people of eastern India the Pracyas and those of western India the Bahikas. The expression *madhyama pratistha du* (the middle fixed region) occurs in the *Aitareya Brahmana*. The inhabitants of this region are stated to be the Kurus, Pancalas, Vasas, and Usinaras. This middle zone is called Aryavarta in the *Baudhayana Dharmasutra* and is described as the area north of the Pariyatra or Paripatra (western Vindhyas), cast of Adarsana (near Kuruksetra), south of the Himavat (Himalaya), and west of Kalakavana (probably near Allahabad).

1.3.3. Post-Vedic Period

Abundant evidence of the geographical knowledge of the Indian people is available in post-Vedic literature. The Epics contain numerous incidental geographical references about the earth in general and Bharatavarsa in particular, the latter being especially dealt with in the *Kiskindha-kanda* of the *Ramayana* and the *Bhisma-parvan* of the *Mahabharata.* Panini's *Astadhyayi* and Patanjali's *Mahabhasya* allude to some of the then prevailing conceptions of the earth and provide considerable details relating to the geography of the subcontinent. Buddhist works like the *Vinaya Pitaka*, *Mahavastu*, and the Nikayas, particularly the *Anguttara Nikaya*, are important sources of geographical information. Indeed, from about the time of Buddha to that of Asoka, Buddhist canonical literature constituted the principal source of geographical information about contemporary India. Even for later periods, the works of Buddhaghosa and the Ceylonese chronicles *Dipavamsa* and *Mahavamsa* provide valuable references. The Buddhist Jataka stories mention various places and add to our geographical knowledge of the country. Chinese Buddhist accounts also throw considerable light on the geography of India. Among the accounts left by Chinese travellers, particular importance is given to those of I-Tsing, Fa Hien, and Hiuen Tsang. The Jain canonical texts and Apabhramsa literature together with the Prabandhas furnish valuable geographical data and supplement the information given by the Buddhist texts.

The Puranas constitute the most detailed and comprehensive source of geographical knowledge of the post-Vedic period. They seem to have originated prior to the fifth or fourth century B.C., but in their present form they cannot be dated earlier than the seventh century A.D. The Puranas draw much of their material from the Epics, but they expand the concepts and furnish greater details. The range of their treatment of the subject covers the 'geography of practically the whole of the old world, the surrounding oceans and observation of some of the atmospheric phenomena. The treatment of geographical information is not uniform in all the Puranas; some go into greater detail than others. The *Vayu*, *Brahmanda*, *Vamana* and *Markandeya*, for instance, contain sections entitled *Bhuvana-kosa*, *Bhuvana-vinyasa*, *Jambudvipavarnana*, and so on, which deal primarily with geographical information.

Kautilya's *Arthasastra* and medical works like the *Caraka* and *Susruta* provide additional details by way of mentioning the natural products of different regions. The astronomical works of Varahamihira, Parasara, and others contribute topographical data regarding the regions of the subcontinent and are valuable sources of the knowledge of mathematical geography which developed in the post-Vedic period. Literary works of Kalidasa, Bana, Kalhana, Rajasekhara, and others also contain geographical references. Epigraphic records arc innumerable and replete with geographical material relating to India and her colonies. In addition to the accounts of Chinese travellers, the reports of foreigners like Megasthenes, Al-Biruni, and Abu'l-Fazl are important eye-witness records of the regions of the subcontinent.

1.3.3.1. The Earth and its Dvipas:

The concept of the earth comprising a number of *dvipas*, meaning continents, seems to have emerged in the post-Vedic period. The *Mahabharata* gives the number of such continents variously in its different sections. In the *Bhisma-parvan* four major *dvipas* are mentioned; elsewhere seven, eleven, and thirteen have been spoken of. The earliest references to the seven-continent theory occur in the *Ramayana*, *Mahabharata*, and Patanjali's *Mahabhasya.* The Pali Buddhist literature mentions four *mahadvipas* (great islands), namely, Uttara-Kuru or Kuru in the north, Jambudvipa in the south, Purva-Videha in the east, and

Apara-Godana in the west, as constituting the earth. The *Mahabharata* gives a description of these four regions, Jambudvipa in particular.

Use of the term *cakravala-rajya* to mean the whole world is also found in Pali literature. The *cakravala* is conceived as ca vast circular plane covered with water with Mount Meru or Mahameru standing at the centre'. Seven *kulacalas* or concentric circles of rock surround Meru. Beyond these are the four great *dvipas*, one in each of the cardinal directions. The post-Gupta Jaina work *Tiloyapannatti* speaks of the earth being constituted of sixteen inner and sixteen outer islands, each having an ocean beyond it.

According to most Puranas, the earth *(prthivi)* consists of seven *dvipas.* These are said to be seven concentric circles of land, like seven rings, one inside the other. The names of the *dvipas* beginning from the innermost are Jambu, Plaksa, Salmali, Kusa, Kraunca, Saka, and Puskara. Each of these *dvipas* is said to be surrounded by a particular sea. Beginning from the innermost, these arc named Lavana (salt-water), Iksu (sugar-cane juice), Sura (wine), Sarpi (ghee), Dadhi (curd), Ksira or Dugdha (milk), and Svadudaka or Jala (fresh-water).

The question which arises is: What is really meant by the Puranic *dvipas* and seas? The Puranas appear to imply by the term *dvipa* 'any land which was ordinarily inaccessible or detached by virtu of its being surrounded by water, sand, swamp or even high mountains or thick forests'. Thus the term may indicate an island, a peninsula, or a doab, or even a specific area of land, large or small, which is distinguished by particular geographical features. It may also stand for tribal or national territories. The Puranic *dvipa* therefore signified 'all types of natural or human regions-big or small.

The descriptions of the seven seas as consisting of sugar-cane juice, wine, etc. should not be taken too literally. They may indicate that these seas had special characteristics which distinguished them from each other. Similar names-the Red Sea, Black Sea, and White Sea, for instance are found even today, but they are not taken in their literal sense. One of the Jataka stories lends credence to the idea that the seas were named after certain characteristics found to be present in them. The story narrates how a ship which was carried off its course by a storm passed in turn through seas named Agnimala (blazing like fire), Dadhimala (the colour of curd), Nilavanna-kusamala, and Nalamala (red like coral). The Epic and Puranic periods are marked by predominance of mythology, albeit not entirely devoid of factual elements. The theory of seven concentric *dvipas* and seas seems to have developed out of this mythological conception of the world. The Puranic writers apparently tried to fit geographical data based on tradition and reports of over-imaginative travellers into a mythological concept.

Most of the Puranas give details of the vegetation, rivers, mountains, climates, etc. of the *dvipas*. Some scholars have, on studying these details, tried to identify specific geographical regions with the *dvipas* spoken of. Even though one may not fully agree with such specific identification, it cannot be denied that the Puranic details of the seven *dvipa* whether based on concrete information (the chain of which has been lost in the course of time) or on limited data supplemented by imagination, do fit in with the geographical features of some of the existing land and water masses on the earth's surface. Reference may be made in this connection to Al-Biruni's (11^{th} C.E) locating the Puskaradvipa between Gina and Mangala (perhaps China and Mongolia).

The Puranas contain an elaborate list of mountains and mountain ranges of the seven *dvipas*. The most commonly mentioned mountain is Meru which is at the centre of the seven *dvipasy* that is, in the centre of Jambudvipa. Similar descriptions of the river systems of the seven *dvipas* occur in the Puranas, signifying familiarity of the contemporary people with the geographical features of not only the regions of their natural habitat but also the old world as a whole.

1.3.3.2. Jambudvipa

Geographical knowledge becomes more intimate as one turns to Jambudvipa. The *Mahabharata* provides a detailed description of Jambudvipa, also called Sudarsanadvipa. It is spoken of as circular in shape. Surrounded on all sides by the sea, it has six mountain ranges running east-west: Himalaya, Hemakuta, Nisadha, Nila, Sveta, and Srngavat. Jambudvipa is divided into nine zones (*varsas*): Hari, Bhadraiva, Ketumala, Bharata, Uttara-Kuru, Sveta, Hiranyaka, Airavata, and Ilavrta. According to Jaina writers, Jambudvipa has seven *varsas* created by six mountain ranges called *varsa-parvatas* running from east to west.

The *Markandeya Purana* describes Jambudvipa as depressed on the south and north and elevated and broad in the middle. This elevated region is Ilavrta (also called Meruvarsa), at the centre of which is the mountain Meru. In different Puranic texts Jambudvipa is said to be composed of the following nine divisions: (i) Ilavrta, (it) Ramyaka or Ramanaka, (iii) Hiranmaya or Hiranyaka, (iv) Uttara-Kuru or Srngasaka, (v) Bhadrasva, (vi)Ketumala, (vii) Hari, (viii) Kimpurusa, and (ix) Bharata. Relative to the central *varsa* Ilavrta, the next three figure in the north, the last three in the south, while Bhadrasva and Ketumala are to the east and west respectively. Four rivers are stated to flow from Meru-Bhadra to the north, Sita to the east, Ganga to the south, and Caksu to the west. There are three mountain ranges north of Ilavrta-Nila, Sveta, and Srngavat-each consecutive range occurring after each successive *varsa*. Similarly, three ranges stand south of Ilavrta: Nisadha, Hemakuta, and Himalaya. To the east and west of Ilavrta running north-south are the Malyavat and Gandhamardana ranges respectively. The descriptions of the three *varsa*s to the north of Meru, some of which are also mentioned in the *Mahabharata* (*Bhisma-parvan*), are rather sketchy in the Puranas.

Nevertheless, the details of the three latitudinal ranges-Nila, Sveta, and Srngavat-of this region, their valleys, river systems, and other information as available in the *Vayu Purana*, make it possible to identify quite a few of their important geographical features. The description of the northern regions of Jambudvipa 'covers a very vast area, from the Urals and the Caspian to the Yenisei and from the Turkestan, Tien-Shan ranges to the Arctic. It describes the topography of the whole land very accurately and in some cases picturesquely. Turning east, Bhadrasva is 'identical with the basins of the Tarim and Hwangho rivers, i.e., the whole of Sinkiang and Northern China'. Ketumala, located to the west of Meru, is irrigated by the river Caksu, which is probably the Oxus. This region corresponds to western Turkestan.

Ketumala is believed to cover 'practically the whole of the ancient Bactria which included the whole of the present Afghan Turkistan (north of Hindukush), the lower Hari Rud Valley, the basin of Murghab Kashka system (all south of the old bed of Amu Darya) and the basins of the Surkhan, Kasirnigan, Vakhsh and Yaksu rivers. Hari appears to have been western Tibet; Kimpurusa was presumably Nepal; and Bharata probably means greater India.

1.3.3.3. Bharatavarsa

The concept of Bharatavarsa as we know it did not emerge apparently before the fourth century B.C., for Panini's *Astadhyayi (c.* fifth century B.C) makes no mention of the southern and extreme eastern regions of the subcontinent. In the third century B.C., however, references to the South Indian peoples like the Colas and Pandyas occur in Katyayana's *varttikas* and in the accounts of Megasthenes. This indicates a growing awareness of the extent of the subcontinent and of the peoples who inhabited it.

The Buddhist and Jain canonical works of the fourth-second centuries B.C. mention sixteen *mahajanapadas* (great states) comprising much of the area of the subcontinent. The nomenclature of the *mahajanapadas* differs in the two traditions. The regions noted in each are mostly confined to the northern and western parts of the subcontinent with occasional reference to the east and south. Asoka's (269-232 B.C.) empire comprised almost the whole of the Indian subcontinent and parts of Afghanistan. This area, which practically corresponds to what subsequently came to be known as Bharatavarsa, is referred to in his inscriptions as *prthivi* and *jambudvipa*. The earliest epigraphic reference to the name 'Bharatavarsa' is found in the Hathigumpha inscription of Kharavela (first century B.C).

The term 'Bharatavarsa' occurring in the *Mahabharata* stands for a vast area comprising numerous rivers, mountains, and territories which are described in some detail. It is not possible, however, to construct a precise geographical outline of this area because the boundaries are not clearly defined. Seven major mountains and ranges are named: (i) Mahendra (Eastern Ghats), (ii) Malaya (Travancore Hills and the southernmost portion of the Western Ghats), (iii) Sahya (Western Ghats to the north of Malaya), (iv)

Suktimat (parts of the Vindhyan range including the Sakti Hills in eastern M.P.), (v) Rksavat (parts of the Vindhyan range to the south of Malwa), (vi) Vindhya (the Vindhyan range from Gujarat to Bihar excluding portions covered by Suktimat, Rksavat, and Paripatra), and (vii) Paripatra or Pariyatra (the Western Vindhyan range including the Aravallis). Among the important rivers mentioned are the Ganga, Sindhu, Sarasvati, Godavari, Narmada, Satadru, Candrabhaga, Iravati, Vipasa, and Yamuna. A list of more than seventy major territorial units *(janapadas)* other than those in the south is given. Among these arc Sindhu, Videha, Magadha, Anga, Vanga, Kalinga, Gandhara, and Kasmira. The southern part of Bharatavarsa is said to include territories like Dravida, Kerala, Malava, Karnataka, and Cola.

Some geographical information about Bharatavarsa, particularly the south, also occurs in the *Ramayana*. Rama's journey from Ayodhya to Kanyakumari, the gateway to Lanka (Sri Lanka), provides the context for describing the forests, rivers, and *janapadas* on the way. Bharata or Bharatavarsa is described in the Puranas as semi-circular and lying between the Himavat in the north and the sea in the south. The *Markandeya Purana* depicts this region as having the Himavat like the string of a bow in the north and the sea in the south, east, and west. The same text gives its shape as conforming to that of a tortoise lying outspread and facing eastward, and also refers to Bharata as being constituted with a fourfold conformation. Bharatavarsa has been spoken of in ancient texts variously as comprising five, seven, and nine divisions.

The *Mahabharata*, a few of the Puranas, Buddhist writers like Hiuen Tsang (7th Cent A.D), and Rajasekhara (9th Cent. A.D) in his *Kavyamimamsa* speak of five regions. These are named (i) Madhyadesa (central), (ii) Udicya (northern), (iii) Pracya (eastern), (iv) Daksinapatha (southern), and (v) Aparanta (western). Madhyadesa has been defined as the land bounded by the Himalayas in the north, the Vindhyas in the south, Vinasana (in Ambala district) in the west, and Prayaga (Allahabad) in the east. Udicya covers eastern Punjab and the Oxus valley including the Himalayas. Its southern boundary may be taken as the river Sutlej. Pracya extends from the eastern end of Madhyadesa to the Assam hills and from the Himalayas to the eastern coastal plain. This region may have included Kasi, Kosala, Videha, and Magadha. Daksinapatha includes the entire area of South India to the south of the Vindhyas. Aparanta is the area lying to the west of Madhyadesa and seems to have comprised Sind, western Rajasthan, Gujarat, and a part of the adjoining coast on the lower course of the Narmada. Reference to a division into seven zones is also found in the *Mahabharata* and most of the Puranas. This classification is not essentially different from that consisting of five regions. In addition to the five already mentioned, the Himalayan region and the Vindhyan range are included as the sixth and seventh divisions.

A third classification which divides Bharatavarsa into nine regions, current in several of the Puranas and the *Kavyamimamsa*, has probably been borrowed from the astronomical works of Parasara and Varahamihira, although likely to be of earlier origin. The *Markandeya Purana* specifies eight of these regions or *khandas* as Indradvipa, Kaierumat, Tamravarna, Gabhastimat, Nagadvipa, Saumya, Gandharva, and Varuna. Regarding the ninth *khanda* it simply says: 'It is this one which is girdled by the sea *(sagarasamvrta)*. The *Kavyamimamsa* names this ninth *khanda* as Kumari; the *Vamana Purana* calls it Kumara; and the *Skanda Purana* designates it as Kumarika. Opinions differ about the identification of these nine divisions. Abu'l-Fazl and Al-Biruni have identified the nine regions within the area of the subcontinent itself. Abu'l-Fazl names seven mountain ranges running east to west between Lanka and Himacala: Mahendra, Sukti, Malaya, Riksa, Pariyatra, Sahya, and Vindhya. The region between Lanka and Mahendra he calls Indradvipa; between Mahendra and Sukti, Kaserumat; between Sukti and Malaya, Tamravarna; between Malaya and Riksa, Gabhastimat; between Riksa and Pariyatra, Nagadvipa; and between Pariyatra and Sahya, Saumya. He divides the area between Sahya and Vindhya into two parts, Kumaradvipa being the eastern section and Varunadvipa the western. Al-Biruni describes Indradvipa as central India; Kascrumat as eastern-central; Tamravarna as south-eastern; Gabhastimat as southern; and Gandharva as north-western. Passages of the *Vayu Purana*, mention that Indradvipa is a region east of the Brahmaputra; Kaserumat is the eastern coastal plain; Tamravarna is the peninsula south of Kaveri; Gabhastimat is the hilly region between the Narmada and the Godavari; Nagadvipa is possibly the area of the Vindhyan and Satpura ranges; Saumya is the coastal belt west of the Indus; Gandharva is the trans-Indus region; and Varuna is the western coast. He does not offer any identification of the ninth *khanda*, unnamed in the *Vayu Purana*.

Some scholars considers that the Puranic conception of Bharatavarsa implies greater India, i.e. India proper plus eight *khandas* outside the area of the subcontinent. Some, identifies Indradvipa with Burma; Kaserumat with the Malay Peninsula; Tamravarna (Tamraparna) with Sri Lanka; Gabhastimat with Laccadive, Maldive, or Ernaculam in the southwest; Nagadvipa with Salsette, Elephanta, and Kathiawar in the west; and Saumya with Kutchin the north-west. Other identifications include Gandharva with the Kabul valley; Varuna with the Indian colony in Central Asia; and the ninth division called Kumari with practically the whole of the Indian subcontinent. Support is lent to this view by the *Kavyamimamsa* which, in course of describing the mountain ranges of the subcontinent, specifically states: 'This is Kumaridvipa.' Similarly, the *Vamana Purana*, after enumerating the peoples of the respective divisions of India proper, concludes by saying that the detailed narration of the countries of Kumaradvipa is now complete.

Further, the list of the *Varaha Purana* replaces the ninth *dvipa* Kumara with the word 'Bharata', suggesting the identity of the two. It seems likely, therefore, that the term 'Bharatavarsa' had both a wider and a narrower connotation and that in the narrower sense it meant India proper. It is well substantiated that Indian colonies were established in the Far East before the Christian era. For nearly fifteen hundred years, and down to a period when the Hindus had lost their independence in their own home, Hindu kings were ruling over Indo-China and the numerous islands of the Indian Archipelago, from Sumatra to New Guinea. Reference may be made in this connection to four inscriptions of King Mulavarman (c. 4th or 5th Century A.D) found in East Borneo, showing that the area was under Indian rule. It is not unreasonable to suppose that these territories were considered a part of greater India and that they might have been included as divisions of Bharatavarsa in the Puranic scheme.

1.3.4. Conclusion

The Indian subcontinent has been from the dim past the home of many races and peoples. Throughout the ancient period this movement of peoples presented a changing panorama. The impact of these tribes and ethnic groups on the soil of India and their efforts to adjust themselves to the opportunities which the geographical environment afforded provides the background of ancient Indian geography. This is perhaps why the Puranas and the astronomical works emphasize the regional conception of geography and take particular note of the *janapadas* and major geographical landmarks. The Puranas follow the tradition dating back to the Vedas of using tribal names to indicate the region which particular tribes inhabited. It is clear that such names are ethnographical in character although territorial or place names are by no means few. In fact, the people of Bharatavarsa appear in the Puranic texts only in their relevant geographical setting, which indicates that in ancient India the different human groups were regarded as so many essential units of a comprehensive geographical system. The lists of *janapadas* occurring in the various Puranas are arranged in an almost identical manner, but there are indications that the lists were altered to receive later additions and were brought up to date from time to time by the inclusion of the names of foreign invaders. Thus there is mention of the Yavanas, Sakas, and Pahlavas of the second and first centuries B.C., as well as of the Hunas of the 5th Cent. A.D. and the Turuskas of the Muslim period. The lists received further alteration with the introduction of the names of *janapadas* and geographical landmarks of newly-explored regions or areas of colonization. Thus, considerable geographical information about Bharatavarsa and the geographical setting of India in ancient period and its neighbourhood is contained in the literary corpus of this land.

1.3.5. Summary

- *In India the earliest references to geographical data are found in the Rg-Veda. Casual references to tribes, rivers, and other geographical landmarks indicate that geographical knowledge was not lacking during the Vedic period.*
- *The ancient Indians conceptions of the universe and the earth determined to a great extent their understanding of the earth's physical properties and conditions.*

- *In Vedic literature the universe is sometimes conceived as consisting of the earth and sky (heaven), and sometimes of the earth, air (atmosphere), and sky. Solar bodies are understood as belonging to the realm of the sky and atmospheric phenomena such as lightning to that of the air.*
- *The semispherical shape of the sky as seen by the eye led to the comparison in the Rg-Veda of the sky and earth to two great bowls (camva) turned towards each other.*
- *The earth is denoted in the Rg-Veda by such words as prthivi (the expansive or large), prthvi or urvi (the broad), mahi (the great), apara (the limitless), and uttana (the stretched out). The Rg-Veda contains references suggesting the spherical shape of the earth. It says, for instance, that every sacrificial altar or ground on the surface of the earth is its centre.*
- *The term dvipa (island) occurs in the Rg-Veda and other Vedic texts. But it is unlikely that the word refers to any island, continent, or major land area as it does in the Epics and Puranas.*
- *Abundant evidence of the geographical knowledge of the Indian people is available in post-Vedic literature. The Epics contain numerous incidental geographical references about the earth in general and Bharatavarsa in particular.*
- *The Puranas constitute the most detailed and comprehensive source of geographical knowledge of the post-Vedic period. The range of their treatment of the subject covers the 'geography of practically the whole of the old world, the surrounding oceans and observation of some of the atmospheric phenomena.*
- *Kautilya's Arthasastra and medical works like the Caraka and Susruta provide additional details by way of mentioning the natural products of different regions.*
- *The astronomical works of Varahamihira, Parasara, and others contribute topographical data regarding the regions of the subcontinent and are valuable sources of the knowledge of mathematical geography which developed in the post-Vedic period.*
- *Literary works of Kalidasa, Bana, Kalhana, Rajasekhara, and others also contain geographical references.*
- *Epigraphic records arc innumerable and replete with geographical material relating to India and her colonies.*
- *The concept of the earth comprising a number of dvipas, meaning continents, seems to have emerged in the post-Vedic period.*
- *Use of the term cakravala-rajya to mean the whole world is also found in Pali literature. The cakravala is conceived as ca vast circular plane covered with water with Mount Meru or Mahameru standing at the centre'.*
- *According to most Puranas, the earth (prthivi) consists of seven dvipas. The descriptions of the seven seas as consisting of sugar-cane juice, wine, etc. should not be taken too literally.*
- *Most of the Puranas give details of the vegetation, rivers, mountains, climates, etc. of the dvipas. The Puranas contain an elaborate list of mountains and mountain ranges of the seven dvipas.*
- *Geographical knowledge becomes more intimate as one turns to Jambudvipa. The concept of Bharatavarsa is an important piece of geographical information found in ancient Indian literature.*

1.3.6. Exercise

- Bring out the geographical information found mentions in the early Vedic literature.
- Discuss the geographical description of Bharatavarsa in the ancient Indian literature.
- How Jambudvipa has been depicted in Post Vedic Literature of India? Discuss.
- Give an account on the earth and the seven island (dvipa) found mention in the ancient Indian literature.
- How Mahabharata describe Bharatavarsa? Discuss.

1.3.7. Further Reading

- Agrawala , V.S., India as Known to Panini, Lucknow University, 1953.
- Cunningham , Alexander , The Ancient Geography o f India. Indological Book House, Varanasi, 1963.
- Dey, N. L., The Geographical Dictionary o f Ancient and Medieval India. Luzac and Co., London, 1927.
- Gibb , H. A. R., Travels in Asia and Africa of Ibn Battuta. Translation. Routlcdge & Kegan Paul Ltd., London, 1957.
- Law, B. C., Geographical Essays Relating to Ancient Geography o f India. Bharatiya Publishing House, Varanasi, 1976.
- Law, B. C., Historical Geography o f Ancient India. Paris, 1954.
- Nainar, M. H., Arab Geographer's Knowledge o f Southern India. University of Madras, 1942.
- Sinoii, M. R., A Critical Study o f the Geographical Data in the Early Puranas. Punthi Pustak, Calcutta, 1972.
- Sircar , D.C., Cosmography and Geography in Early Indian Literature. Indian Studies, Calcutta, 1967.
- Sircar , D.C., Studies in the Geography o f Ancient and Medieval India. Motilal Banarsidass, Varanasi, I960.
- S. M. Ali, Geography o f the Puranas. People’s Publishing House, New Delhi, 1966.
- Upadhyaya , B. S., India in Kalidasa. S. Chand and Co., Calcutta, 1968.

****

Unit-2

Chapter-I

SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENTS IN MEDIEVAL INDIA; Influence of the Islamic World and Europe; the role of *Maktabs, Madrasas* and *Karkhanas* set up.

Structure

2.1.0. Objectives

This chapter investigate the growth of sciences in Indian during the period from 8^{th} to 18^{th} century A.D. After reading this lesson you will be able to:

- *discuss the educational practices that emerged during the medieval period;*
- *trace the developments in science & technology in Medieval India;*
- *assess the influence of Arabian and Persian science in India in the period under discussion and*
- *list some well known scholars in the field of science & technology and their works during this period.*

2.1.1. Introduction

Muslim rule started in India with the unset of 13^{th} century A.D. and lasted for around five hundred year and concluded with the death of Emperor Aurangzeb in 1707. During this period considerable work was done in various sphere of science and technology. Sciences such as mathematics, medicine, astrology, astronomy flourished. It is also true that in Medieval India, science was not patronized as a state policy by Kings or the Raja's. It is also unfortunate that science and technology was not pursued rigorously as it was being developed in Europe. Huge monuments were constructed, observatory were built, texts were translated but the volume was too low in comparison to the west. Inspite of all these hurdles, sciences flourished in a scanty manner. This chapter endeavor to throw light on the influence of Arabian world and subsequent growth of various aspects of science during medieval phase of Indian history.

2.1.2. Sciences in Medieval Age

By this time, the traditional indigenous classical learning had already received a setback. The pattern of education as prevalent in Arab countries was gradually adopted during this period. As a result, Maktabs and Madrasas came into existence. These institutions used to receive royal patronage. A chain of madrasas, opened at several places, followed a set curriculum. The two brothers, Sheikh Abdullah and Sheikh Azizullah, who were specialists in rational science, headed the madrasas at Sambal and Agra. Apart from the talent available locally in the country, learned men from Arabia, Persia and Central Asia were also invited to take charge of education in madrasas.

The Muslim rulers attempted to reform the curriculum of primary schools. Some important subjects like Arithmetic, Mensuration, Geometry, Astronomy, Accountancy, Public Administration and Agriculture were included in the courses of studies for primary education. Though special efforts were made by the ruler to carry out reforms in education, yet sciences did not make much headway. Efforts were made to seek a kind of synthesis between the Indian traditional scientific culture and the prevalent medieval approach to science in other countries. Let us now see what developments took place in various fields during this period.

Large workshops called karkhanas were maintained to supply provision, stores and equipments to royal household and government departments. The karkhanas not only worked as manufacturing agencies, but also served as centres for technical and vocational training to young people. The karkhanas trained and turned out artisans and craftspersons in different branches, who later on set up their own independent karkhanas.

2.1.2.1. Mathematics:

Several works in the field of Mathematics were produced during this period. Narayana Pandit, son of Narsimha Daivajna was well known for his works in Mathematics-Ganitakaumudi and Bijaganitavatamsa. Gangadhara, in Gujarat, wrote Lilavati Karamdipika, Suddhantadipika , and Lilavati Vyakhya. These were famous treatises which gave rules for trigonometrical terms like sine, cosine tangent and cotangent. Nilakantha Somasutvan produced Tantrasamgraha, which also contains rules of trigonometrical functions.

Ganesa Daivajna produced Buddhivilasini-a commentary on lilavati-containing a number of illustrations. Krishna of the Valhalla family brought out Navankura on the Bijaganit of Bhaskara-II and elaboration of the rules of indeterminate equations of the first and second orders. Nilakantha Jyotirvida compiled Tajik, introducing a large number of Persian technical terms. Faizi, at the behest of Akbar, translated Bhaskara's Bijaganit. Akbar ordered to make Mathematics as a subject of study, among others in the education system . Naisiru'd –din-at –tusi, was another scholar of Mathematics.

2.1.2.2. Biology

Similarly, there were advancements in the field of Biology. Hamsadeva compiled a work in the field of Biology entitledMrga-paksi-sastra in the thirteenth century. This gives a general, though not always scientific, account of some animals and birds of hunting. The Muslim kings, who were warriors and hunters, maintained a fleet of animals such as horses, dogs, cheetahs and falcons for hunting. Animals, both domesticated as well as wild, have been described. Both Babur and Akbar, in spite of being busy in their political preoccupations and war, found time to study the work. Akbar had a special interest in producing good breeds of domestic animals like elephants and horses. Jahangir, in his work - Tuzuk-ijahangiri - recorded his observations and experiments on breeding and hybridization. . He described about 36 species of animals. His court artists, specially, Mansur, produced elegant and accurate portraitures of animals. Some of these are still preserved in several museums and private collections. As a naturalist, Jahangir was also interested in the study of plants. His court artists have drawn around 57 plants in their floral portraitures.

2.1.2.3. Chemistry

Do you know that in the medieval period, use of paper had begun? An important application of Chemistry was in the production of paper. Kashmir, Sialkot, Zafarabad, Patna, Murshidabad, Ahmedabad, Aurangabad and Mysore became well known centres of paper production. The paper making technique was more or less the same throughout the country differing only in preparation of the pulp from different raw materials.

The Mughals knew the technique of production of gunpowder and its use in gunnery, another application of Chemistry. The Indian crafts persons learnt the technique in evolved suitable explosive composition. The work Sukraniti attributed to Sukracarya contains a description of how gunpowder can be prepared using saltpeter, sulphur and charcoal in different ratios for use in different types of guns.. The principal type of fireworks included those which pierce through air, produce sparks of fire, blaze with various colours and end with explosion. The work Ain-I-akbari speaks of the regulation of the Perfume office of Akbar. The attar (perfume) of roses was a popular perfume, which is supposed to have been discovered by Nurjehan.

2.1.2.4. Astronomy

Astronomy was another field that flourished during this period. In astronomy, a number of commentaries dealing with the already established astronomical notions appeared. Mehendra Suri, a court astronomer of Emperor Firoz Shah, developed an astronomical, instrument 'Yantraja'. Paramesvara and Mahabhaskariya, both in Kerala, were famous families of astronomers and almanac-makers. Nilakantha Somasutvan produced commentary of Aryabhatiyaa. Kamalakar studied the Islamic astronomical ideas. He was an authority on Islamic knowledge. Maharaja Sawai Jai Singh-II of Jaipur was a patron of Astronomy. He set up the five astronomical observatories in Delhi, Ujjain, Varansasi, Mathura and Jaipur.

2.1.2.5. Medicine

The Ayurveda system of medicine did not progress as vigorously as it did in the ancient period because of lack of royal patronage. However, some important treatises on Ayurveda like the Sarangdhara Samhita and Chikitsasamgraha by Vangasena, the Yagaratbajara and the Bhavaprakasa of Bhavamisra were compiled. The Sarangdhara Samhita, written in the thirteenth century, includes use of opium in its material medica and urine examination for diagnostic purpose. The drugs mentioned include metallic preparation of the rasachikitsa system and even imported drugs.

The Rasachikitsa system, dealt principally with a host of mineral medicines, both mercurial and non-mercurial. The Siddha system mostly prevalent in Tamil Nadu was attributed to the reputed Siddhas, who were supposed to have evolved many life-prolonging compositions, rich in mineral medicines.

The Unani Tibb system of medicine flourished in India during the medieval period. Ali- in Rabban summarized the whole system of Greek medicine as well as the Indian medical knowledge in the book, Firdausu-Hikmat. The Unani medicine system came to India along with the Muslims by about the eleventh century and soon found patronage for its growth. Hakim Diya Muhammad compiled a book, Majiny-e-Diyae, incorporating the Arabic, Persian and Ayurvedic medical knowledge. Firoz Shah Tughalaq wrote a book, Tibbe Firozshahi. The Tibbi Aurangzebi, dedicated to Aurangzeb, is based on Ayurvedic sources. The Musalajati-Darshikohi of Nuruddin Muhammad, dedicated to Darashikoh, deals with Greek medicine and contains, at the end, almost the whole of Ayurvedic material medica.

2.1.2.6. Agriculture

In the medieval period, the pattern of agricultural practices was more or less the same as that in early India. Some important changes occurred in the introduction of new crops, trees as well as horticultural plants by foreign traders. The principal crops were wheat, rice, barley, millets, pulses, oilseeds, cotton, sugar-cane and indigo. The Western Ghats continued to yield black pepper of good quality and Kashmir maintained its tradition for saffron and fruits. Ginger and cinnamon from Tamil Nadu, cardamom, sandalwood and coconut from Kerala, were becoming increasingly popular. Tobacco, chillies, potato, guava, custard apple, cashew and pineapple were the important plants which were introduced to India during the sixteenth and seventeenth centuries. It was during this period that the production of opium from poppy plants began in Malwa and Bihar regions. Improved horticultural methods were adopted with great success. The systematic mango-grafting was introduced by the Jesuits of Goa in the middle of sixteenth century. Imperial Mughal Gardens were suitable areas where extensive cultivation of fruit trees came up.

For irrigation, wells, tanks, canals, rahat, charas and dhenkli charas (a sort of a bucket made of leather used to lift water with the help of yoked oxen) were used. Persian wheel was used in the Agra region. In the medieval period, agriculture was placed on a solid foundation by the State by introducing a system of land measurement and land classification, beneficial both to the rulers as well as the tillers.

2.1.3. Influence of Arabian Sciences in India

The scientific cooperation between India and the Arabs dates back to the time of Abbasid Caliphate of Baghdad when a number of books on astronomy, mathematics, and medicine were translated from Sanskrit into Arabic. From then on the ancient scientific knowledge of India continued to influence Muslim scientists. Arab interest in Hindu sciences was parallel to their interest in Greek learning.

The cooperation begin with the time of Caliph al-Mansur (CE.753-774). The Caliph, not only caused the translation of Brahma-siddantha, but also he asked for a work to be prepared from it which might serve as foundation for computing the motions of the planets. This was done by Ibrahim al-Fazari and Yaqub Ibn Tariq in cooperation with Hindu pundits in 750 and the book was called Al-Zij ʿala Sini al-ʿArab, or Sindhand al-Kabir.

This Siddhanta translation was possibly the vehicle by means of which the Indian numerals were transmitted from India to Baghdad. With the help of these Hindu Pundits, Al-Fazari, translated Brahmagupta's other book Khandakhadyaka and gave it the Arabic name of Arkand. Both works were extensively used, and exercised great influence in the development of astronomy in the Islamic world. It was on this occasion that the Arabs first became acquainted with the Hindu system of astronomy. They learned astronomy from Brahmagupta (7th Cent.AD) earlier than Alexandrian scientist Ptolemy.

The Greek and Sanskrit texts on mathematics and astronomy were used by Muslim scientists as bedrock to develop new fields. Hindu mathematics left a more lasting impression on the Arab sciences. What we call today Arabic numerals, were in fact Indian numbers. The Arabic word for numbers is Hindsah, which means from India. This way of writing numbers, including the way to write a 'zero', was very exciting to mathematicians. Arab scientists in Iraq, especially Muhammd ibn Musa al-Khawrizmi (CE 9th Cent) used the new numbers to develop algebra. The English word algorithm is derived from his name. Some mathematical and astronomical terms were borrowed from Sanskrit. Ethical writings of Chankya (Shanaq) and works on logic and magic were translated as catalogued by Ibn Nadim in his 10th century Kitab al-

Fihrist. Ibn al-Muqaffa translated Pancatantra into Arabic as Kalila wa Dimna. The fascinating story of Sindbad was partly of Indian origin. Parts of Mahabharata were rendered into Arabic by Ali Jabali, in C.1026.

A large number of Sanskrit medical, pharmacological and toxicological texts were translated into Arabic under the patronage of Khalid Barmaki, the vizier of Caliph Al- Mansur. Indian medical knowledge was given a further boost under Caliph Harun al Rashid (786-809) who ordered the translation of Susrata Samhita into Arabic. For over five hundred years Muslim & other writers continued to apply to works on arithmetic the name Indian. Prime Minister Yahya bin Khalid Barmaki deputed ambassadors to India to invite distinguished scholars, physicians, & philosophers to Baghdad. In appointing translators, the Caliph made no distinction of creed or color. The Muslims were very keen on informing themselves of the customs, sciences, and religions of the people whom they came into contact with. Yaqoob Kindi's (873) account of India was based on the evidence of the envoys sent to India to procure medicines and to report on Indian religions. Ali Ibn Hyusayn Masudi (956) visited India and wrote about Hindu beliefs, their history from legends, and complimented them on their achievements in their sciences as the 'cleverest among the dark people'. Baghdad's book seller Ibn al-Nadim, al-Biruni, al-Ashari, Shahrastani and many other writers devoted chapters in their books to Indian religions and sciences. Al-Nubakhti's Kitab al-ara-I wal adnya-i-Madhahib al-Hind mentioned by Masudi was perhaps the earliest study of Hindu sects. Sulayman the merchant visited India about 851 and praised Hindi proficiency in medicine, astronomy and philosophy. Contact with Hindu sciences came to an end when the political grip of Baghdad on Sind was loosened.

During the Mughal rule of India, science & technology developed mainly due to the interests of Emperors and Sultans, particularly in astronomy, agriculture, engineering, architecture and medicine. A number of encyclopaedias and dictionaries were penned. Initially dictionaries were needed as new ideas were being developed as a result of interaction between Sanskrit and other languages. During the later period of Mughal rule, new ideas were accepted from European science and technology. In sciences the Hindus had developed elaborate systems in mathematics, astronomy and medicine; the Muslims were obliged to Hindus and Greeks for these departments of knowledge. In due time Muslims built up original structures of their own scientific systems. When Muslims arrived in India they brought their own knowledge which was not inferior to Hindus. The Hindus did not disdain to incorporate what they found new. Thus the Hindus astronomers took from the Muslims a number of technical terms, the Muslim calculation of longitudes and latitudes, and various other items of calendar, Zij.

Abu Rehan al-Biruni (d.1053) was the first scientist of Islam who made a deep study of Hindu sciences. He was the first scholar to study India and the Hindu scientific literature. He has been described as the founder of Indology. He studied Sanskrit diligently and was so proficient in it that he could translate into, as well as from Sanskrit. Hindu scholars gave him the title of Vidya-sagar (ocean of knowledge). Until the 10th century, history most often meant political and military history, but this was not so with him. In his Tahqiq-al-Hind, he described India's cultural, scientific, social and religious history. Due to military incursions of King Mahmud of Ghazna in India, Hindu scholars had moved to remote religious centers. In this charged atmosphere Biruni imposed upon himself the strict discipline of scientific objectivity. He tried to explain Hindu doctrines without any bias, avoiding any kind of polemics.

Biruni's approach to Hindu sciences was comparative, making analogies between Greek and Hindu civilizations. His comparison of two civilizations led him to the conclusion that Hindus could not bring sciences to classical perfection, and that scientific theories of the Hindus "are in a state of utter confusion, devoid of any logical order, and in the last instance always mixed up with the silly notions of the crowd". (Kitab-al-Hind) Biruni regarded the essence of Hindu religion as a form of monotheism, idol worship as ignorant passions of the people. He was the first to introduce the study of Bhagavad Gita to the Muslim world, and the first Muslim to study the Puranas and to translate Patanjali and Samkhya into Arabic. In considerable detail he outlined the principles of Hindu astronomy, geography, mathematics and medicine.

Biruni translated a Sanskrit book Batakal, as Bátanjal. From this work he extracted a great deal which he made use of in his magnum opus Qánún Mas'údi, a 1500 page work on mathematics, geometry and astronomy. All that the sages of India have said about numbers, ages, and eras (tawarikh), has been exactly given by Abu Rehan in his translation of the Batakal.

2.1.4. Curiosity of Sultans of Delhi

Sultans of Delhi Jalal al-Din Khilji (d.1296) is the first Muslim sultan of Delhi to have showed some intellectual curiosity for Hindu learning and Sanskrit studies. Sultan Muhammad bin Tughlaq (1351) was a great scholar versed in logic, Greek philosophy, mathematics, astronomy and physical sciences. He had knowledge of medicine and was skillful in dialectics. He also was an expert calligrapher. He enjoyed the society of Hindu yogis and extended his patronage to Jain divines. Zia al-Din Nakhsabi's adaptation of 52 short stories from Sanskrit into Persian in 1330 entitled Tuti Nama (Book of Parrot) is the outstanding achievement of Tughlaq's reign in this field.

The Sultans of Delhi were very much interested in mechanical machines like pulleys and piers. In the book Sirat Feroz Shahi (1370) 13 such instruments were listed which were used in transporting stones and heavy building materials. A manuscript of Sirat is preserved at Bankipur library. During the rule of Sultan Nasir Shah (1500-11) a scholar by the name of Muhammad ibn Daud translated many Arabic books into Persian which was then the official language of the state. Sultan Firoz Shah Tughlaq (1388) allowed more than a third of a million pounds (36 lacs) to learned men and pious endowments. A number of Madrassas were opened to encourage literacy. He set up hospitals for free treatment of the poor and encouraged physicians in the development of Unani medicine. He commissioned translations of medical works from Sanskrit. He ordered a work on Hindu astronomy and astrology to be translated into Persian under the name of Dalaile Firoz Shahi. Works on music and wrestling were also translated. Ziya al-Din Barani (1357), wrote a chronological history of Tughlaq's rule, entitled Tarikh-i-Firoz Shahi. Genuine interest and patronage of Sanskrit learning began with Sultan Zain al-Abidin of Kashmir (1420-1470) who commissioned the translations of Mahabharta and Raja-tarangini into Kashmiri language, which was first indication of Muslim interest in the pre-Muslim Hindu history of India.

2.1.5. Intellectual curiosity of Emperor Akbar

The Mughal Emperors (1526-1858) took a keen interest in the development of astronomy. They patronized astronomers in their royal courts. The works thus produced were mainly zijes (astronomical tables) and calendars. Many scientific works brought from outside of India like Bahauddin Amuli's (1574-1621) Khulasa tul-Hasab, and Tusi's Tahrir Uqlidis and Tahrir al-Majisti. Attempts were made to write commentaries and translate these works. As a result the intermingling of Indian mathematical tradition with Arabic & Persian did take place enriching the country.

Emperor Humayun (1556) built a personal observatory near Delhi, while Jahangir and Shah Jahan were also intending to build observatories but were unable to do so. Mulla Chand, a court astronomer of Emperor Nasiruddin Humayun produced "Tashil Mulla Chand", which was a redaction of Zije Ulugh Beg. Muslim patronage of Hindu learning reached its highest watermark in the court of Emperor Jalal al-Din Akbar (d.1605). Some of the Hindu nobles in his court wrote in Persian and Sanskrit, like Raja Manohardas and Raja Todar Mal (d.1589) who translated Bhagavata Purana into Persian. Akbar had a stupendous library composed entirely of manuscripts written and engraved by skilful penmen. The volumes in his library numbered only 24,000 but they valued at $3,500,000. He patronized poets and learned men. He supervised the translation of Mahabharta into Persian. In the preface to his Persian translation of Mahabharata, Abul Fazl says: "Akbar initiated a policy so that in his age the pillars of blind following were demolished and a new era of research and enquiry in religions matters commenced". In 1578 he ordered Abul Fazl to translate the New Testament into Persian. No copy of this translation is extant, but it appears he made the translation with the help of the Catholic Fathers. The translation of Ramayana was undertaken by Abdul Qadir Badauni on the express command of Akbar in 1585 and completed in 1590. The Harivamsa Purana, supplement to Mahabharta, was translated by eminent Persian poet Mulla Sheri.

A translation bureau Maktab Khana was established in the Diwan Khana of Fatehpur Sikri, its members included Faizi, Abul Fazl, Naqib Khan, Badauni and Shirazi. The Sanskrit scholars explained the original to the Persian scholars, who made the translation s into a literary language. All the translations of Sanskrit works prepared during Akbar's reign were illustrated by the court painters.

Some Muslim nobles like Abdul Rahim Khani-i- Khana, Abul Fazl and Faizi knew some Sanskrit and translated from it. In 1584 Akbar ordered Mulla Abdul Qadir Badauni to translate from Sanskrit into Persian Singhasan Battisi, embodying the stories of Bikarmajit and the 32 statutes. A learned Brahmin was appointed to be Badauni's collaborator to interpret Sanskrit text for him. The Persian work was entitled Naama-i-Khirad (The Wisdom Augmenting Book). Next year Akbar ordered Abul Fazl to translate from Arabic into Persian Hayatul Haiwan, the celebrated zoological dictionary, compendium of folklore, and popular medicine, authored by Musa al-Damiri (d1406). Faizi paraphrased the first two puranas into Persian verse. Taj al-Ma'ali translated a Sanskrit work and called Mufarrih al-Qulub, manuscript is at Indian Office library, MS 3350.

Father Monserrate presented to Akbar an Atlas sent to him by Archbishop of Goa. He had written in his travelogue that he had seen Akbar working on machines and giving instructions on how to make new machines. This is how he described Emperor Akbar: "He is a great patron of learning, and always keeps around him erudite men, who are directed to discuss before him philosophy, theology, and religion, and to recount to him the history of great kings and glorious deeds of the past. He has an excellent judgment and a good memory, and has attained to a considerable knowledge of many subjects by means of constant and patient listening to such discussions. Thus he not only makes up for his ignorance of letters (for he is entirely unable either to read or write), but he has also become able clearly and lucidly to expound difficult matters. He can give his opinion on any question so shrewdly and keenly, that no one who did not know that he is illiterate would suppose him to be anything but very learned and erudite." The Commentary of Father Monserrate, on his Journey to the Court of Akbar 1591.

Shaikh Abu al-Faiz ibn Mubarak-pen name Faizi (1547-95) was a poet laureate of Emperor Akbar. At the suggestion of Akbar, Faizi translated Bhaskar Acarya's (1114-60) Sanskrit work on mathematics Lilavati into Persian in 1587; containing theorems of arithmetic and algebra. The translation was so popular that Ataullah Rashdi Lahori translated Bhaskar Acarya other books on algebra and measurement. Faizi, a prodigious author of 100 books, translated few mathematical problems from Latin into Persian also. The famous book covering the administration of Emperor Akbar, AIn-I-Akbari written by Abul Fazl Allami ibn Mubarak (d.1602), described West and Central Asian astronomy. Abu-al-Fażl's greatest literary accomplishment was the monumental Akbar-nāmah in 3 volumes. Among his many works is a Persian translation of the Bible.

Authors of later generations admired his style and sought to imitate it. Zije Ulugh Beg, prepared by Sultan Ulugh Beg (1393-1449) in Samarkand was translated into Sanskrit, entitled Ulakabegijica.

2.1.6. Knowledge System

The medieval period marks the coming of Muslims in India. By this time; the traditional indigenous classical learning had already received a setback. The pattern of education as prevalent in Arab countries was gradually adopted during this period. As a result, Maktabs and Madrasas came into existence. These institutions used to receive royal patronage. A chain of madrasas, opened at several places, followed a set curriculum. Apart from the talent available locally in the country, learned men from Arabia, Persia and Central Asia were also invited to take charge of education in madrasas. Some important subjects like Arithmetic, Mensuration, Geometry, Astronomy, Accountancy, Public Administration and Agriculture were included in the courses of studies for primary education. Though special efforts were made by the ruler to carry out reforms in education, yet sciences did not make much headway. Efforts were made to seek a kind of synthesis between the Indian traditional scientific culture and the prevalent medieval approach to science in other countries. Let us now see what developments took place in various fields during this period. Large workshops called karkhanas were maintained to supply provision, stores and equipments to royal household and government departments. The karkhanas not only worked as manufacturing agencies, but also served as centres for technical and vocational training to young people. The karkhanas trained and turned out artisans and crafts persons in different branches, who later on set up their own independent karkhanas. The Royal workshops (Karkhanas) played an important role in the administrative system of the Sultanate. The needs of the royal household were met through Karkhanas. The Karkhanas were of two types - (i) Manufacturing place (ii) Store House. Under Feroz Tughlaq, there were as many as 36 Karkhanas. Each Karkhana was supervised by a noble who had the rank of a Malik or a Khan.

2.1.7. Conclusion

During the Muslim rule of India considerable work was done in mathematics, medicine, astrology, astronomy, and translations of various texts. Custodians of faith filled the minds of people with superficial things and did not allow enquiry into religious dogmas. Science was not patronized as a state policy by Kings or the Raja's. It is unfortunate science and technology was not pursued rigorously as it was being developed in Europe. No scientific institutions were set up, nor were students sent to Europe for higher studies. The money that was spent on constructing monumental edifices, had it been spent on creating scientific institutions, India could have become an advanced country long time ago.

2.1.8. Summary

- *There was a considerable change in the education system. The Arabic system was introduced in a big way. Madrasas and Maktabs were established all over. The rulers tried to introduce reforms.*
- *Several works were written in the fields of Mathematics, Chemistry, Biology, Astronomy and Medicine.*
- *Most of the scientific works in this period were commentaries or expositions of the earlier treatises.*
- *Several important scientific works in astronomy, medicine and other sciences were rendered from Sanskrit to Persian/Arabic and from Persian/Arabic to Sanskrit.*

2.1.9. Exercise

- Describe the education system that developed during the medieval period.
- Discuss the developments in the field of Medicine during the medieval period.
- Give an account on the role of Medieval rulers for the growth of sciences in India.
- Write an essay on "Science and Scientists during the medieval period.
- To what extent Medieval Indian Sciences influenced by the west Asian sciences? discuss.

2.1.10. Further Reading

- Taher, M., Educational Developments in the Muslim World, Dehli, 1997.
- Rogers, A., Tuzuk-i-Jahangiri -Or Memoirs Of Jahangir, London, 1914.
- Chanda, Tara., Influence of Islam on Indian Culture, Lahore, 1979.
- Elgood, C., Medicine in India, New York, 1934.
- Ashri, S.B., Delhi's Jantar Mantar Observatory, New Delhi, 2005
- Volwahsen, Andreas., Cosmic Architecture of India, Astronomical Monuments of Jai Singh, London, 2001.
- Al-Hasan, A.Y., Science & Technology in Islam, UNESCO, 2001.
- Mukhopadhyaya , G. N., History o f Indian Medicine (3 Vols.). Calcutta University, 1923
- Jaggi, O. P., *Science and Technology in Medieval India.* Atma Ram & Sons, Delhi, 1977.
- Taton , Rene (Ed.), History of Science: Ancient Medieval Science from the Beginnings to 1450. Translation, Thames & Hudson, London, 1963.

*****

Unit-2

Chapter-II

DEVELOPMENTS IN THE VARIOUS FIELDS OF SCIENCES

Mathematics, Astronomy, Chemistry and Medicine

Structure

2.2.0. Objectives

In this chapter we intended providing you an insight into the historical development of various sciences during medieval phase of Indian history. By the end of this chapter the learners would be able to:

- *to know the condition of astronomy in India in the post-Aryabhatta period to 18th century A.D;.*
- *to trace in brief the growth of mathematics in Indian subcontinent during 8th to 18th century;*
- *to assess the status of Chemical science during Muslim rule in India;*
- *to study the development, practice and importance of Medical Sciences under the patronization of Medieval Indian rulers.*

2.2.1. Introduction

The medieval period marks the coming of Muslims in India. By this time, the traditional indigenous classical learning had already received a setback. The pattern of education as prevalent in Arab countries was gradually adopted during this period. As a result, Maktabs and Madrasas came into existence. These institutions used to receive royal patronage. A chain of madrasas, opened at several places, followed a set curriculum. Some important subjects like Arithmetic, Mensuration, Geometry, Astronomy, Accountancy, Public Administration and Agriculture were included in the courses of studies for primary education during this period. Though special efforts were made by the ruler to carry out reforms in education, yet sciences did not make much headway. Efforts were made to seek a kind of synthesis between the Indian traditional scientific culture and the prevalent medieval approach to science in other countries. During the medieval period, Science and Technology in India developed two facets: one concerned with the already chartered course of earlier traditions and other with the new influences which came up as a result of Islamic and European impact. Let us now see what developments took place in various fields during this period.

2.2.2. Mathematics in Medieval India

Most of the available Sanskrit literature was translated during the Muslim rule of India, and in some instances Muslims made significant contributions. Euclid's Elements was translated into Arabic by Allama Nasiruddin Tusi, while Qutub al-Din Sherazi had translated it in 1311 into Persian. Based on these translations, Abdul Hamid Muharrar Ghaznavi wrote Dastur al-Bab fee Ilm al-Hisab after 26 years of intensive labor.

One of the distinguished families of Punjab that made significant contributions to mathematics was Ustad Ahmad Lahori, aka Ahmad al-Mima'r, (1580-1649) the architect of Taj Mahal & Red Fort. One of his sons Ataullah Rashedi translated Bijganita during the reign of Emperor Shah Jahan. He also wrote Khulasa Raaz in Persian which dealt with arithmetic, algebra, and measurement. His other book Khazinatul A'adad dealt with arithmetic, geometry of Euclid and algebra. Another son Lutfullah Muhandis wrote Risala Khaws A'adad dealing with properties of numbers. He was also author of Sharah Khulasa al-Hisab and his Muntakhebat was a translation of Persian mathematician Bahauddin Aamili's Khulasa tul-Hisab .

Imad al-Din Riyadi, the grandson of Ustad Ahmad was also a versatile scientist. He wrote a commentary on Amuli's Khulasa tul-Hisab, entitled Hashiya bar Sharah Khulasa which consisted of a preface, ten chapters and an appendix. Besides these he wrote a commentary on Sharah Chaghmani entitled Hashiya bar Sharah Chaghmani. He also wrote a book on problems of spherical astronomy and geometry. On music he authored Risala Dar Ilm Museekee which covered a wide range of topics on philosophy. It appears that mathematics was not only associated with accountancy and revenue collection, but with astronomy and architecture as well. A number of translations were made from Persian & Arabic into Sanskrit. Maharajh Sawai Singh made major contributions in trigonometry, which was to find the sine of one degree and its parts, namely minutes and seconds.

Abul Khair Khairullah, another grandson of Ustad Ahmad Lahori, wrote a commentary on Zij Muhammad Shahi, translated Almagest as well as wrote a commentary on it. He was appointed director of the Dehli observatory in 1718. His other major works were: Majmu'a al-Madkhil fil al-Najoom & Majmu'a al-Saboot al-Qudsia. Khazinatul Ilm or Treasury of Knowledge was a Persian book by Khawaja Azimabadi dealing with arithmetic, geometry, astronomy along with English terminology and their translations into Persian. This is also reflected in the works of Fakhruddin Khan Bahadur, author of Risala dar Biyan Amal al-Qata and Shamsul Hindsa, which are on measurement, geometry and trigonometry.

2.2.3. Astronomy In Medieval India

In the second half of 20th century several new astronomical manuscripts, both original works and commentaries, have been critically edited, translated, and commented upon by a number of able scholars in India and abroad throwing new light on the development of astronomy in medieval period of India. It now appears that the originality of Indian astronomy did not cease with the astronomical and mathematical productions of Bhaskara II in the beginning of the twelfth century, that both before and after him important works and commentaries were produced, and further that the medieval period from the twelfth to the eighteenth century, though largely marked by the secondary activities of the commentators, did occasionally produce brilliant minds with significant contributions to their credit. The following few paragraphs will discuss the development of astronomy in medieval India.

2.2.3.1. Astronomy in Early Medieval Phase

During the early medieval period Between the great astronomer and mathematicians Brahmagupta and that of Bhaskara II, in Indian subcontinent host of intellectuals like Govindasvamin, Sankaranarayana, Aiyabhata II, Sripati, and Satananda flourished. They with their work created an intellectual atmosphere for the growth of astronomy in India.

Govindasvamin (c.800-850) is mainly noted for his commentary on the Mahabhaskanya and, therefore, for his mastery of the Aryabhafan system. He was the court astronomer of King Ravivarman of Kerala. Besides the commentary, he is credited with an original work on astronomy and mathematics called Govindakrti of which references are known but the original manuscript is still untraceable. Govindasvamin's disciple and younger contemporary, Sankaranarayana (c.825-900), also rose to eminence through his commentary on the Laghubhdskariya, and was appointed chief court astronomer of Ravivarman of the Cera dynasty of Kerala.

Vaskara (b.880), whom al-Birunl referred to as Vitteswara in his book on India, was another scholar who flourished in North India. We learn from his own statement that he was the son of Mahadatta Bhatta, a native of Anandapura in the Punjab. His Siddhanta is a voluminous work divided into three main sections, each subdivided into a number of chapters. It is well known that Brahmagupta in his Brahmasphutasiddhanta, written at a young age, indulged in invectives against Aryabhata for his sophisticated theories, e.g. the rotation of the earth and the equal division of the mahayuga.

Aryabhata II (c.950) did not have the merit of his namesake and illustrious predecessor. His Mahasiddhanta is a compendious work based largely on orthodox views, showing some originality in the treatment of indeterminate equations. The reputation of versatile ***Sripati*** (c. 999), son of Nagadeva, is based on his (i) Dhikoti, a Karana work on the Aryabhatiya, (ii) a fuller astronomical work entitled Siddhanta-Ukhara, and (iii) a mathematical treatise, Ganitatilaka. He is credited with the discovery of the moon's second inequality. ***Satananda*** (c. eleventh century) hailed from Puri in Orissa and wrote a Karana work called Bhasvati, more or less in the style of the Surya-siddhanta. This work enjoyed great popularity among the astronomers and almanac-makers of the eastern region.

Despite a few original works, this period witnessed by and large the production of a number of commentaries and secondary works. It would, however, be unrealistic to characterize this period as one of commentaries only. This type of literature started appearing from the eighth or ninth century, if not earlier. ***Utpala*** was a great commentator who specialized on Varahamihira. In the ninth century ***Prthudakasvamin*** (c. 860) produced two important commentaries on Brahmagupta, namely, the Brahmasiddhanla-vawnabhasya and Khandakhadyaka-vivarana.

2.2.3.2. Period from Thirteenth to Eighteenth Century

In the thirteenth century another Aryabhatan scholiast, Suryadeva Yajvan (c. 1191-1250), hailing from Kerala, produced a number of commentaries on the Aryabhatiya, Manjula's Laghumanasa, and the works of Bhaskara I. His commentary on Aryabhata has been published, in the critical edition of Aryabhatiya, by the Indian National Science Academy on the occasion of the fifteen hundredth birth anniversary of the great savant. Suryadeva was also an astrologer of repute and commented on Varahamihira's Mahayatrd and Sripati's Karmapaddhati.

The fourteenth and fifteenth centuries are remarkable for the production of both commentaries and original works. Mahendra Suri (c. 1320), a disciple of Madana Suri and native of Bhrgupura in North India, was one of the principal court astronomers of Firozshah Tughluq. The Suri family mastered the theory and technique of the astrolabe, the versatile astronomical instrument and computer. This is borne out by the Yantraraja or Yantrarajagama compiled by Mahendra Suri from Persian sources. Malayendu Suri, his disciple, prepared a useful commentary on the tract.

In the South (Kerala) flourished Madhava of Sangamagrama (c. 1340-1425), who later on received the appellation 'Master of Spherics' (golavid). In his Venvaroha he developed an easy and facile procedure for determining the true position of the moon every 36 minutes. The motion of the moon is not only the fastest among planets and stars, but is marked by maximum and rapid changes which render extremely difficult the determination of its correct position at any intermediate time during the day. He developed an accurate moon-mnemonics, correct to the second, which gradually became widely accepted by Keralan astronomers. This creative method became the subject of several tracts, e.g. the Candra-sphutapi, Vertoarohakriya, and Drg-venvarohakriya, all anonymous, and another work, Vinvarohastaka, ascribed to Putumana Somayaji. In the Venvaroha Madhava uses an epoch beginning from a .d . 1400 on the basis of which his time has been ascertained without much ambiguity. The Venvaroha is not his only work. He is credited with several other works such as the Lagnaprakarana, a table of moon-mnemonics, Mahajyanayanaprakara, Madhyamdnayana-prakara, Aganita, and Aganita-paheangay about the definite identification of which some disputes still persist.

Paramesvara (c.1360-1455), another versatile astronomer and prolific commentator of Kerala, developed a system of computation following Haridatta's earlier parahita system with a view to ensuring better agreement between observations and theoretical computations. A disciple of Rudra, lie belonged to a family of astronomers who lived in the village of Allatur near the confluence of the river Nila with the Arabian Sea. His original works include Drgganita (1430), Goladipika (1443), Vakyakarana, Grahanaslaka, Grahanamandana, and Candracchaya-ganita, most of which are small but useful tracts. His detailed running commentaries on the Aryabhatiya, Mahabhaskanya, Laghubhaskariya, Swya-siddhanta, Laghumanasa, and Lilavali dearly show his mastery of traditional astronomy of the Siddhantic period and at the same time his indefatigable energy as a commentator. From the point of view of clarity and brevity of expression he was probably unrivalled.

Paramesvara's son, Damodara (c. 1410-1510), imbibed his father's interest and scholarship in astronomy. Damodara's works have not yet come to light, but that lie did write certain astronomical works is attested by the statements of his illustrious disciple Nilakantha Somayaji (1444-1545). Nilakantha is also known by other titles such as 'Somasutvan', 'Somasut', and their Malayalam version 'Goinatiri'. As a commentator and innovator, he attained widespread fame which compares well with that of Paramesvara. From the scanty biographical details given in the colophon of his commentary on the Ganita section of the Aryabhatiya and from a Malayalam work, Laghuramayanam, we learn that he was a Namputiri of the Garga gotra and hailed from Silkundapura or Srikundagrama (Malayalam, Tr-k-kanti-yur) near Tirur in South Malabar, a place which in medieval times rose to be an important seat of Sanskrit learning, specially astronomy and mathematics. As to his teachers, besides Damodara, he mentions another preceptor, Ravi, versed in Vedanta. In his Siddhanta-darpana he refers to these two teachers.

Of the several works penned by Nilakantha, special mention may be made of Golasara (Essence of the Sphere), Siddhanta-darpana (Mirror of Astronomy), Candracchaya-ganita (Computations of the Moon's Shadow), Tantrasangraha (Collection of Astronomical Works), and Aryabhatiya-bhasya (Commentary on the Aryabhatiya). Moreover, he wrote commentaries on his own Siddhantadarpana and Candracchaya-ganita. Some other minor works of Nilakantha include the Grahana-nirnaya (Determination of Eclipses) and Sundararaja-prasnottara (a debate with the Tamil astronomer Sundararaja on the method of vakyakarana and other astronomical procedures). And this by no means exhausts the list of his writings, some of which are yet to be traced.

Nilakantha's commentary on the Aryabhatiya is a masterpiece despite several other commentaries on this text by renowned astronomers like Bhaskara I, Paramesvara, and Suryadeva Yajvan. He not only elucidated with singular clarity many cryptic verses composed in the sutra style, but expressed his profound admiration for Aryabhata for his insistence on periodic observations in order to ensure accuracy. Nilakantha himself kept up this spirit and advocated without reserve the importance of astronomical observations, specially during eclipses. He emphasized that such 'experimentation should continue to be done by successive generations of disciples and grand disciples.

In the fifteenth-sixteenth centuries, although the extreme South-Kerala and Tamil countries-had the pride of place in astronomical research and in keeping the subject alive through commentaries, the astronomers of countries south and north of the Vindhyas were no less active. Gangadhara, author of Candramana (1434), lived south of the Vindhyas and Makaranda of Varanasi, who compiled handy tables based on the Surya-siddhanta, became popular with almanac-makers, as did Laksmidasa for his Ganitatattva-cintamani (1500), a commentary on the Siddhanta-siromani of Bhaskara II. We also hear of several families of astronomers and mathematicians, some of whom were prolific writers.

It is interesting to note that while Aryabhata was popular among, and dominated the astronomical thinking of, scholars in the South, the Suryasiddhanta attracted the greatest attention of the astronomers of the North. The works of Bhaskara II, Siddhanta-siromani, Lilavati, and Bijaganita, were popular throughout India. From the time of Mahendra Suri in the fourteenth century up to that of Kamalakara in the seventeenth, during which some astronomers were closely associated with the House of Tughluqs and later on of the Moguls, many opportunities arose for the exchange of astronomical and mathematical ideas between the two streams of scholarship, of which the fullest advantage was obviously not taken. A better synthesis was attempted towards the end of the seventeenth and the beginning of the eighteenth centuries under the inspiring patronage of Sawai Jai Singh II (1686-1734), who was himself an accomplished astronomer and was able to attract a number of distinguished scholars of different religious faiths. More of this later.

2.2.3.3. Growth of Astronomy under Persian Influence:

The Persian-Indo polymath, Fatehullah Sherazi (d.1582), a scientist at the court of Emperor Akbar (d.1605) reformed the Calendar. One of his inventions, a military weapon, was designed for killing infantry, an early volley gun with multiple gun barrels similar to hand cannons. Fariduddin Munajjum, a court astronomer of Shah Jahan (d.1666), compiled Zije Shah Jehani. The first section of the tables dealt with various calendars, second section dealt with spherical astronomy, third section dealt with determination of the motions of the planets and their positions in the sky. The Zij was translated into Sanskrit under the title Siddhanta-Sindhu, by Nityananda at the command of vizier Asaf Khan & completed in 1635. The Sanskrit translations consisted of 440 pages, 11 copies of this written on 'jahazi' paper, 45x33 cm were distributed among the aristocrats of North India. Four copies are at Jaipur palace library. Nityananda explained the Arabic and Persian technical terms for the benefit of Hindu astronomers while giving differences between Islamic and Hindu astronomy. He devised new technical terms during the translations, which were later used in the translations Phillipe de Hire's Latin tables into Sanskrit.

Malajeet was an astronomer at Shah Jahan's court. He wrote Parsiprakasa (1643) which gave Arabic, Persian astronomical terms and their Sanskrit equivalents. Two Hindu scholars namely Nitya Naad, & Menisvara, used Arabic, Persian and Greek works to synthesize Islamic traditions with those of India. Mulla Mahmud Jaunpuri was a versatile scholar, expert in mathematics and astronomy. His book Shamsay Bazegha and Shamsey Baligha bring out outstanding features of astronomy. Emperor Shah Jehan wanted to construct an observatory for Mulla Jaunpuri, but could not do so on account of financial constraints on the royal treasury.

2.2.3.4. Maharajah Sawai Jai Singh

Maharajah Sawai Jai Singh (d.1743) was an astronomer of the first order. He had some Greek works on mathematics (including Euclid) translated into Sanskrit as well as more recent European works on trigonometry, logarithms and Arabic texts on astronomy. As he found the prevalent tables in use at that time defective, he decided to prepare new ones. First he built metal instruments which, however, did not come up to his idea of accuracy. Therefore he constructed at Delhi huge masonry instruments. Subsequently, to verify the correctness of his observations, he constructed instruments of the same type in Jaipur, Mathura, Banaras and Ujjain observatories. In his five observatories Hindu and Muslim observers were employed and produced a set of astronomical tables called Zijey Jadid Muhammad Shahee. He was fluent in Persian and Arabic and was acquainted with Zij-i-Ulugh Beg. He incorporated in his works latest European astronomical knowledge as is evidenced from the Zij which was based on Latin tables of Phillipe de Hire.

There is evidence that Rajah used a telescope for his observations of the celestial bodies. This telescope was brought by Father Bandier who had visited Jaipur. His observations of Venus and Mercury, the rings of Saturn and Sunspots are proof that he employed a telescope. The 16th and 17th centuries saw a synthesis between Islamic astronomy and Indian astronomy, where Islamic observational techniques and instruments were combined with Hindu computational techniques. While there appears to have been little concern for theoretical astronomy, Muslim and Hindu astronomers in India continued to make advances in observational astronomy and produced nearly 100 Zij treatises. Jai Singh’s brahman tutor Samrat Jagannath, translated Allama Nasiruddin Tusi’s Tahrir al-Majisti into Sanskrit entitled Samrat Siddhanta in 1732. He also translated Tusi’s Kitab Usul al-Hindasa which was based on Euclid’s Elements. Nayansuk-hopadhaya translated Tusi’s Tahrir al-Ukar into Sanskrit entitled Ukara. A manuscript is preserved at Jaipur Museum library. Yantra-prakara was composed for Raja Jayasimha in Dehli in 1729 based on Tahrir al-Majisti, later translated into Sanskrit by Jagannath.

Descriptions of 275 astronomical manuscripts still housed in the palace library of Jaipur help clarify how Raja Jaya Simha was led to rely on observations for practical astronomy and on European theories for accurate calculations of celestial phenomena.

Seamless Globes: Fathullah Shirazi (c. 1582), a Persian-Indian polymath and mechanical engineer who worked for Akbar the Great in the Mughal Empire, developed a Volley gun. Considered one of the most remarkable feats in metallurgy, the seamless globe was invented in Kashmir by Ali Kashmiri ibn Luqman in 1589-90, and twenty other such globes were later produced in Lahore and Kashmir during the Mughal Empire. Before they were rediscovered in the 1980s, it was believed by modern metallurgists to be technically impossible to produce metal globes without any seams, even with modern technology. Another famous series of seamless celestial globes was produced using a lost-wax casting method in the Mughal Empire in 1659-1960 by Muhammad Salih Tahtawi (from Thatta, Sind) with Arabic and Persian inscriptions. It is considered a major feat in metallurgy. These Mughal metallurgists pioneered the method of wax casting while producing these seamless globes.

Instruments: Astrolabe used for astronomical observations was developed and improved upon in India. Humayun patronized astrolabe manufacturing. The astrolabe maker at his court was Allahdab Asturlabi Lahori whose sons and grandsons also made astrolabes. Lahore seemed to have been a major centre for the manufacture of astronomical instruments. Maharajh Jai Singh constructed a number of astrolabes which were made from masonry, i.e. Smarat Yantra, Jai Prakash, Ram Yantra, Misra Yantra.

The instruments and observational techniques used at the Mughal observatories were mainly derived from the Islamic tradition, and the computational techniques from the Hindu tradition. In particular, one of the most remarkable astronomical instruments invented in Mughal India is the seamless celestial globe. Spanish astronomer & instrument maker Ibrahim Al-Zarqali’s (1087) treatise on the universal astrolabe Safiha was translated into Sanskrit as Jarakali-Yantra by Nayansukhophadhaya and was incorporated into Jagan Nath’s Siddhanta Kaustubya around 1730.

2.2.3.5. Synthesis Between Hindu and Arabic Astronomy

Reference has already been made to sporadic efforts on the part of Hindu astronomers to incorporate elements of Arabic astronomy and mathematics in Sanskrit works. At least there were ample opportunities for studying Greek works in Arabic translations. In 1259 Hulagu Khan, after the conquest of Persia and establishment of his capital in Maragha, south of Tabriz, decided to set up on the top of a hill near his new capital an astronomical observatory. With royal patronage and the devoted labour of a number of leading astronomers of his time, the observatory developed into a fine and most well-equipped centre for first-rate astronomical work. Nasir al-Din at-Tusi, a renowned astronomer and mathematician, was its first director, and the Syrian engineer and astronomer al-Dimiski, as well as al-Khalati of Tiflis, al-Maraghi, al-Maghribi, Abu'l Faraz, ibn al-Futt, and several other astronomers and mathematicians worked here and produced the famous astronomical tabic al-ilkhani. It also built up unrivalled library. Unfortunately the observatory did not last long, for we do not hear further about it from the fourteenth century onward. In the following century Ulugh Beg, another Mongol prince in the direct line of Timur and great patron of learning, particularly of astronomy, compensated for the decline of Maragha by establishing another grand observatory in Samarkand in Central Asia.

These examples had some effect in India only in the beginning of the eighteenth century when Sawai Jai Singh (1686-1734), an able statesman and astronomer, decided to build in Jaipur, Delhi, Ujjain, and a few other places observatories equipped with masonry and other instruments for the purpose of making more accurate observations and preparing more reliable astronomical tables. In all this he followed the methods and practices of Arab astronomers, retaining at the same time many standard methods given in traditional Sanskrit texts. His masonry instruments included a giant right-triangular gnomon fitted with a graduated quadrant called Samrat Tantra; a hollow hemispherical dial, the jai prakai, provided on its concave surface with a number of coordinates; a cylindrical instrument called Rama Tantra, provided with graduations on its inside wall and on the floor believed to be a type of cylindrical astrolabe; and other instruments to serve the purpose of the meridian circle, meridional arc, zodiacal circle, etc. Ja i Singh greatly appreciated and valued the small brass instrument called the 'astrolabe* in the manufacture of which Islamic instrument-makers had specialized. He encouraged fabrication of such instruments with Sanskrit inscriptions and himself wrote a small tract on the subject.

The research programme he and his able astronomers and observers undertook included the compilation of an improved astronomical table, Jij Muhammad shahiy and translation into Sanskrit of Ptolemy's Almagest, Euclid's Elements, and a few other texts from their Arabic versions. The first two were rendered by Jagannatha (b. 1652) who, at the instance of his patron, mastered Arabic and Persian to carry out this important task. Jai Singh also came in contact with a number of Christian missionaries and learnt from them the progress made in astronomy through new types of instruments such as the telescope. He took steps to procure through Jesuit channels the latest astronomical works by European authorities. We know from Tieffenthaler, a Jesuit missionary who visited India just after the death of Jai Singh, that many Jesuit astronomers, including himself, had intended to work in Jai Singh's observatories and initiate a process of exchange of ideas and methods of immense consequence for the future development of Indian astronomy. That, however, was not to be due to the premature death of the patron and astronomer king and the darkening political clouds soon to engulf the country into a century of strife and uncertainty.

The astrolabe to which reference has been made a number of times arrived in India with Muslim astronomers or astronomical instrument-makers. The information as to when and how it came to India and the extent of popularity attained by it in astronomical circles is very imperfect. As to the origin of the instrument itself, it appears to be a Greek invention-Hipparchus (150 B.C.), Apollonius (260-200 B.C.), and Eudoxus (350 B.C.) being variously credited with the knowledge of stereographic projection, the basic principle of the instrument. Curiously enough, the instrument is not mentioned in the Almagest. But Ptolemy was certainly acquainted with the instrument, for he wrote a tract on stereographic projection which was translated into Arabic in the tenth century and from Arabic into Latin in the twelfth. In the fourth century a .d

. Theon of Alexandria wrote a small tract in which the term 'little astrolabe' was first used. The first full-fledged work on the astrolabe is that of Philloponus (c. a .d . 530). About a hundred years later Severus Sebokht produced another tract, clearly based on Thcon's work.

The credit of real development in astrolabe-making, however, goes to Arab astronomers and instrument-makers, starting from around the ninth century. Thus al-Fazari (c. 800), one of the earliest Muslim astronomers, wrote a tract on the subject. Other notable early astronomers of Arab culture areas who wrote important tracts on the astrolabe include Abu'l-Ma'shar, Umar al-Balkhi, 'Ali ibn Isa of Baghdad, al-Farghani (c. 830), al-Biruni (973-1048), al-Majriti of Cordova (c. 1000), al-Zarkali (c. 1029), and Nasir al-Din al-Tusi (1201-74). Al-Blruni's two tracts on the instrument, Comprehensive Study on Possible Methods for the Construction of the Astrolabe and The Book of Instructions in the Elements of the Art of Astrology, attained great popularity and arc available in translations in European languages.

Of the three main types of astrolabes, i.e. the flat or plani-sphaerum, spherical, and linear, the first type is the most common. By the skilful use of the astrolabe with its plates and various graduations, it is possible to tell time during day and night, find positions of the sun and stars, solve problems of heights and distances, make other computations, and, above all, teach the elements of astronomy.

India has a good collection of astrolabes, imported as well as locally made. Among the old astrolabes, a thirteenth-century one inscribed in Kufic characters is now kept in the collection of the Archaeological Museum at the Red Fort, Delhi. During the sixteenth and seventeenth centuries India produced a number of highly skilled astrolabe makers whose instruments are to be found in this country and in various museums of the world, particularly the History of Science Museum at Oxford. A large number of them bear the names of the members of the family of Shaikh Allah-Dad (f. 1570), who established his reputation as a master astrolabist in Lahore during the reign of Humayun. This tradition continued with distinction in the fourth generation by Allah-Dad's great grandson piya al-Dln Muhammad (c. 1650).

When the Hindu-Arabic synthesis was thus taking place, the ancient and medieval science of astronomy had lost much of its force and value. Europeans had already arrived and started their survey and other scientific operations with much improved and more powerful instruments.

2.2.4. Chemistry in Medieval India

Chemistry in medieval India was closely associated with alchemy which was an integral part of the Tantric cult. Although the origin of alchemy in India may be traced to a date as far back as that of the Atharva-Veda, or even that of the Rg-Veda, practical alchemy reached its peak only during the Tantric period. Alchemy, as is well known, has a twofold objective: (i) the preparation of an elixir of life and (ii) the production of the philosophers' stone for the transmutation of base metals into gold. Tantric treatises, both Brahmanical and Buddhist, abound in recipes for such transmutation of base metals, particularly of mercury into gold. The Rasaratnakara, attributed to the famous Buddhist alchemist Nagarjuna, contains descriptions of alchemical processes and preparations of many mercurial compounds.

It gives an account of many chemical processes like the extraction of zinc, mercury, and copper, and the preparation of crystalline red sulphide of mercury (svarnasindura or makaradhvaja). This medicament is still used as a panacea for many ailments by physicians in India following the indigenous system of medicine. The treatise also describes more than two dozen varieties of apparatuses (yaniras) for carrying out various physico-chemical processes like distillation, sublimation, extraction, calcinations, digestion, evaporation, filtration, fumigation, fusion, pulverization, heating by steam and by sand, and the preparation of many metallic compounds.

The Rasarnava or Devisastra (twelfth century), a Tantra of the Saiva cult dealing with alchemy and chemistry, gives a description of the colours imparted to flames by various metallic compounds like those of copper, tin, lead, and iron. A variety of minerals and ores, the extraction of copper from pyrites and zinc from calamine, the distillation of alum (possibly giving rise to sulphuric acid), and the purification of mercury by distillation are described in this Tantric text.

The alchemical ideas and treatises of India found their way to China and Tibet. The Dhatuvada (c. eighth-ninth century), a Tantric text in Sanskrit, found translated in the Tanjur division of Tibetan literature, gives an account of the deposition of copper on iron from a copper salt solution and the preparations of amalgams of copper and of white lead. The Sarvekararasoyana, another Tantric text in Sanskrit of the same time which is also translated in the Tanjur, explains the process of making cuprous sulphide. The preparation of antimony by heating a mixture of stibnite and iron is mentioned in the Rasendracudamani (thirteenth century). This shows that the process was known in India much earlier than its discovery in Europe by Basil Valentine (1604).

The preparations of calomel and of oil of vitriol (sulphuric acid) from alum, the use of alum as a mordant for dyes, and the extraction of zinc from calamine are described in the Rasaprakasa-sudhakara (c. thirteenth century). The ideas of the alchemists about the possibility of transmuting base metals into gold gradually lost their charm because of repeated failure of experiments. But the numerous preparations of mercury, iron, copper, and other metals obtained in the process came to be used in medicine. As a result, the compilation of a number of medical treatises dealing with the use of metallic preparations followed. One such work, the Buddhist treatise Rasaratna-samuccaya, contains a vast mass of the then existing chemical information but very little that is new and of intrinsic value. It treats of mercury, minerals, metals, gems, liquefaction, incineration, construction of apparatuses, purification of metals, and extraction of essences (active principles). A beautiful description of the location, construction, and equipment of a chemical laboratory is recorded in this treatise. A method of preparing mineral acids, particularly aqua-regia (tankha-dravarasa), by distillation has been given in the Rasapradipa (c. 1535).Unlike what happened in Europe, alchemy in India failed to develop into rational, scientific chemistry. As a result, it gradually became extinct.

2.2.4.1. Practical application of Chemistry in Medieval Age

There is plenty of evidence of the application of chemical knowledge and processes in the medieval period, particularly relating to metallurgy and metal-working, gunpowder, saltpeter, mineral acids, alum, paper, ink, soap, and cosmetics. Heavy guns and cannons made of copper, bronze, and brass were used by the Mogul emperors. Instances of working with wrought iron on a large scale by means of forging and hammering are provided by the following: the iron pillar at Dhar (fourteenth century); the pillar on Mount Abu (fourteenth century); the large iron beams at Konarak and in the temples of Puri (c. twelfth century); and the big iron guns and cannons of the Mogul period as found at Bijapur, Hyderabad, and Murshidabad. Records of the preparation of steel swords at various places in India arc found in the Juktikalpataru (c. eleventh century) and Sarngadhara-padabali (c. fourteenth century).

The tinning of copper vessels gained currency in India from the Middle Ages, possibly after the arrival of the Muslims. An alloy made of copper, lead, and tin, or of copper, lead, and zinc known as bidery (from Bider, a town in Andhra Pradesh), produced during this period, was used to make vases, basins, cups, etc. which were then inlaid with gold and silver. These products were made largely in Hyderabad, Bengal, and North-West India. Enameling on gold and silver ornaments in different colours with metallic oxides mixed with soda-lead glass was known all over India. From the beginning of the seventeenth century, or possibly even earlier, a method of recovering gold remaining as waste of gold working was in vogue. In this process the waste materials were boiled in an aqueous solution of a mixture of nitre, common salt, and alum. This solution evidently contained aqua regia. Gunpowder was introduced in India about the time of Babur (c. 1483-1530). Formulas for the manufacture of fireworks are found in the Kautuka-cintamani and the Akasa-bhairava-kalpa of the fifteenth century. The preparation of mineral acids (dilute aqua regia) is described in several medical works composed in the sixteenth and seventeenth centuries.

Paper-making was introduced in India from China through Nepal in about A.D. 1000 and became a flourishing industry during the Mogul and Peshwa periods. The raw materials used were mainly worn-out clothes, old tents, barks of certain shrubs and trees, and similar substances. These were beaten into a pulp in a lime-lined water reservoir and then made into paper sheets with the help of moulds. Soap, made in India for the first time during the Mogul period, was prepared from trona or natron, common salt, sesamum oil, and goat's suet. The preparation of black ink in solid and liquid forms from lampblack, gum, and the infusion of gallnut in water has been described in the Rasaratnakara of Nityanatha (thirteenth century). The preparation of cosmetics and perfumes was known from the sixth century A.D. A detailed description of several aromatic ingredients for the preparation of cosmetics and perfumes, and the technical processes and recipes for the preparation of different perfumed products are given in the Gandhasara, which is composed around A.D. 1000 on the basis of earlier texts dating from A.D. 500 to 1000.

2.2.4.2. Chemical Technology

Chemical technology during the Muslim rule was centered on five areas: 1. Preparation of drugs 2.preparation of perfumes and cosmetics 3.preparation of beverages including fermented ones 4.making of dyes 5.making gun-powder, and pyrotechnics. Rockets were also made with gunpowder in them. Some rockets went in the air and some went along the surface.

Tipu Sultan (d.1799) and his father Hyder Ali (d.1782) are regarded as pioneers in the use of solid fuel rocket technology or missiles for military use. A military tactic they developed was the use of mass attacks with rocket brigades on infantry formations. Tipu Sultan wrote a military manual called Fathul Mujahidin in which 200 rocket men were assigned to each Mysore a "cushoon" (brigade). Mysore had 16 to 24 cushoons of infantry. The areas of town where rockets and fireworks were manufactured were known as Taramandal Pet ("Galaxy Market"). It was only after Tipu's death that the technology eventually reached Europe.

The rocket men were trained to launch their rockets at an angle calculated from the diameter of the cylinder and the distance to the target. In addition, wheeled rocket launchers capable of launching five to ten rockets almost simultaneously were used in war. Rockets could be of various sizes, but usually consisted of a tube of soft hammered iron about 8 inches (20 cm) long and 1.5 to 3 in (3.8 to 7.6 cm) in diameter, closed at one end and strapped to a shaft of bamboo about 4 ft (1 m) long. The iron tube acted as a combustion chamber and contained well packed black powder propellant. A rocket carrying about one pound of powder could travel almost 1,000 yards. In contrast, rockets in Europe, not being iron cased, could not take large chamber pressures and as a consequence, were not capable of reaching distances anywhere near as great.

There was a regular Rocket Corps in the Mysore Army, beginning with about 1200 men in Hyder Ali's time. At the Battle of Pollilur (1780), during the Second Anglo-Mysore War, Colonel William Baillie's ammunition stores are thought to have been detonated by a hit from one of Hyder Ali's rockets, contributing to a humiliating British defeat. After the fall of Srirangapattana, 600 launchers, 700 serviceable rockets and 9,000 empty rockets were found. Some of the rockets had pierced cylinders, to allow them to act like incendiaries, while some had iron points or steel blades bound to the bamboo. By attaching these blades to rockets they became very unstable towards the end of their flight causing the blades to spin around like flying scythes, cutting down all in their path. These experiences eventually led the Royal Woolwich Arsenal to start a military rocket research and development program in 1801, based on the Mysorean technology. Their first demonstration of solid-fuel rockets came in 1805 and was followed by publication of A Concise Account of the Origin and Progress of the Rocket System in 1807 by William.

2.2.4.3. Conclusion

Chemistry in India was developed empirically and occupied itself, more or less, with the collection of accidentally discovered facts associated with various practical arts like ceramics, metallurgy, metal-working, and medicinal preparations without any recognition of the chemical principles or nature of the chemical changes involved in their pursuit. The result was that the thoughts and ideas could not germinate into scientific laws and theories based on experimental observations and verifications. Likewise, the mechanical skill displayed in the pursuit of practical arts could not develop into technology in the absence of guidance and suggestions from scientific knowledge. Chemistry was dominated more by seeing and believing than by thinking and knowing. After the age of Nagarjuna, Indian treatises provide very little new chemical information, though quite a large number of commentaries and compilations were composed till the end of the sixteenth century. Nevertheless, India's achievements in the use of minerals, metallurgical techniques, processing of chemicals of everyday use, extraction of metals from their ores, and craftsmanship in the manufacture of certain metal products, which required mastery of some chemical processes, were quite remarkable. Some of the technical skills exhibited by ancient Indian chemists and metallurgists were indeed noteworthy.

2.2.5. Medical Science

Medical Science was always a fascinating subject practices actively in all ages of human history. It was during the medieval age Indian medicinal science dominated earlier by Ayurveda , was witnessed severe changes. Even Ayurveda also changed its course. New medical practices such as Unani arrived in India by the Arabian. The Arabian influence bring changes in medical practice, primacy and pharmacology.

2.2.5.1. Changing nature of Ayurveda

A new type of Ayurvedic treatment, rasacikitsa, which incorporated iatrochemistry or metallic compounds, came into vogue from c. A.D. 1300. It sought to utilize bodily fluids (rasa) for repelling diseases and preventing senility, and thereby acquiring a long life. Numerous preparations of mercury, iron, copper, and other metals as formulated in alchemy were found to be helpful accessories in medicine. Mercury became a principal healing substance, of which numerous preparations are described in different iatro-chemical texts and even in general works on Ayurveda of the medieval period. Opium and several other foreign drugs were incorporated into Ayurvedic pharmacology in about A.D 1500. Mineral acids, tinctures, and essences also came to be used about the same time.

2.2.5.2. Persian Influence on Medicine

Muslim practitioners were known by their designation Hakim or Tabib. Hakim means a scientist or a learned man while Tabib means a physician. The Jarah was a surgeon, surgery was called Ilmey Jarahat. Most of the medical & scientific books were written in Arabic and Persian. Islamic medicine in India was founded on books of two Persian physicians, namely Zakariya Razi and Hakim ibn Sena. During the rule of Tegin (1098-1127) a scholar from Khawrazm Hakim Zainuddin Ibrahim Ismail wrote a book on medicine called Zakhirah Khawazim. This compendium asserted great influence in India from 12th to the 15th century. The book described definition of medicine, diagnosis of an illness, reasons for illness, fevers, types of poisons and constitution of human body. He also wrote another book Aghraz al-Tibb which was also very popular among the local practitioners of medicine. His Tibbey Yadgar was an extensive pharmacopeia in 14 chapters.

Physician Nafees Ibn Kirmani (d.1424) wrote a book entitled Tibbey Akbari. Hakim Mansur ibn Ahmad was a Persian who had settled in Kashmir. He authored a book Kafaya al-Mujahideen, on the diseases of women and children and their treatment. This was dedicated to Sikandar Shah II of Dehli. One of the secretaries of Emperor Humayun Yusuf ibn Muhammad Herati wrote a book on various diseases and their remedies. Muhammad Momin wrote Tuhfatul Mominin which was a compilation of various Arabic & Sanskrit authorities, on the whole field of medicine. Madan al-Shifa Sikandar Shahi was written in 1512 by Beva-bin-Khas., a vizier of Sultan Sikandar Lodhi, synthesizing Islamic and Sanskrit medicine. Famous historian Hindu Shah wrote Dastul al-Ittiba'a. Hakim Nooruddin Abdulla was a nephew of abul-Fazl, vizier of Akbar. He wrote a book Alfaz al-Adwiyya on material medica giving names in Hindi, Arabic, Persian, Latin, Spanish, Turkish and Sanskrit. The book was dedicated to Emperor Shah Jahan.

Hakim Ali Gilani (1554-1609) was not only a physician but a renowned mathematician and a scientist. He was attached to the court of Akbar who had given him the title of Jalinoos al-Zaman (Galen of the world). He was the only Indian physician to have written a commentary of all five volumes of al-Qanun. The first volume of the commentary Jamay al-Sharahein was published from Lucknow in 1850. Another book of his on medicine is called Mujarrabatey Gilani (tested remedies). Emperor Jahangir believed that Akbar was poisoned by Hakim Gilani. Muhammad Raza of Shiraz wrote a treatise Riaz-i- Alamgiri on medicine, food and clothing, and was dedicated to Aurangzeb. Muhammad Akbar Arzani, court physician of Aurangzeb, wrote Tibb-i-Akbari in 1678, which was in fact translation of Sharh -ul-Asbab. Arzani also wrote Tajriba-i-Akbari, based on author's own experiences. His Qarabadain Qadri was an extensive pharmacopeia of medicine extensively used in India. Imam Ghulam Hakim wrote in Persian Elaj al-Ghuraba (treatment of special diseases) which was reprinted several times during the 19th century due to its immense usefulness.

Hakim ‘Alavi Khan was born in Shiraz, in Persia, in 1670. In 1699 he went to India and presented himself at the Mughal court of Afghans, where he was appointed physician to Prince Muhammad A‘zam (who was later to rule for only three months in 1707). The Mughal ruler Bahadur Shah (ruled. 1707-12) gave him the title ‘Alavi Khan. Muhammad Shah (reg.1719-1748), the Mughal ruler in Delhi, raised him to the rank of Shash-hazari and gave him the title of Mu‘tamad al-Muluk. When the Persian ruler Nadir Shah defeated Muhammad Shah and sacked Delhi, ‘Alavi Khan accompanied Nadir Shah when he left India and ‘Alavi Khan accepted the position of Hakim-bashi ("chief physician") to Nadir Shah. After making a pilgrimage to Mecca, ‘Alavi Khan returned to Delhi in 1743 and died there about four years later. He wrote four medical treatises in Arabic and four in Persian. His nephew Muhammad Husayn ibn Muhammad Hadi al-‘Aqili al-‘Alavi al-Khurasani al-Shirazi (fl. 1771-81), known as Hakim Muhammad Hadikhan, used ‘Alavi Khan's pharmacopoeia titled Jami‘ al-javami‘-i Muhammad- Shahi, which was dedicated to the Mughal ruler Muhammad Shah. A large portion of this comprehensive work written in 1771 is on simple and compound remedies. Sihatul Amraz by Pir Muhammad Gujrati 1726 contained prescriptions for cure of all diseases. Following is a list of medieval undated medical manuscripts preserved in India.

- Khulasat –ut-Tibb: by Muhammad bin Masood, a short treatise on medicine, on the art of dying, and paper making.
- Asrar-i-Ittiba: by Shihab al-Din, essays on the virtues of amulets, medicine, charm for averting disease.
- Shifa ar-Rijal: Shihab al-Din, poetical treatise on medicine
- Bahr-ul-Manafia: 1794 by Maulood Muhammad, dedicated to Tipu Sultan, treatise on midwifery, children, exorcising devils, enchantments etc.
- Qanun-dar-Ilm-Tibb: a translation by order of Tipu Sultan, a complete pharmacopeia.
- Tarjuma Kitab-i-Farang: a translation of Dr Cookburn’s treatise on twist of the intestines.
- Mufradat dar-Ilm-Tibb: on botany and natural history, translated by order Tipu Sultan from French & English.
- Risala Tib-i-Aspan: translation from Sanskrit by Zain al-Din 1519 and dedicated to Shamsuddin Muzafar Shah on farriery.
- Kitab al-Sumum: by Shanka of India, translated into Persian by Hatim, later by Abbas Saeed Jauhari.
- Sharah Hadae-tul-Hikma: by Muhammad bin Ibrahim, qazi of Shiraz, contains the whole course on sciences read in schools. It was much esteemed by Muslims of India.
- Makhzanul Adwiyya: by Hakim Muhammad Hussin, printed in Persian.
- Tazkira-tul-Hind: by Hakim Razi Ali Khan, on materia medica in Persian, written in early part of 19th century, lighographed in 1866 Hyderbabad.

In the 17th and 18th century when Persian medicine almost died in Iran, it was kept alive in India. Cyril Elgood observes, “ When Persian medicine almost died of inanition in Persia, it was kept alive by the Hakims of Delhi & Lucknow. Its literature was preserved by the printing presses of northern India. It was to them that we owe the first printed editions of such famous works as Tashrih-i-Mansuri, Tuhfatul Momineen, and Tuhfatul Ashiqeen of Avicenna.”

2.3.5.3. Pharmacy

Sultan Alauddin Khilji (1296-1316) had several eminent Hakims in his royal courts. This royal patronage was a major factor in the development of Unani practice in India, but also of Greco-Islamic (Unani) medical literature with the aid of Indian Ayurvedic physicians. During the reign of Moghul kings of India several Qarabadains were compiled like Qarabadain Shifae’ee, Qarabadain Zakai, Qarabadain Qadri and Elaj-ul-Amraz. In these pharmacopoeias quantities of drugs in a given prescription were specified, and methods of preparation. The court physicians supervised the preparations of royal medicine, which were sealed to ensure safety. Hakeem Ali Gilani was the chief physician of Emperor Akbar and used to accompany him in his travels. Hakim Gilani used to carry his pharmacy with him in these travels. He invented a kind of sweet wine for getting rid of traveling fatigue. During the reign of Emperor Jahangir, Itr-i-Jahangiri was discovered by Queen Noor Jahan. Hakim Ain-ul-Mulk Shirazi composed for his royal patron emperor Shah Jahan Alfaz-al-Adwiyya (vocabulary of drugs). It was printed in 1793 in Calcutta, and rendered into English by Gladwin. Hakim Akbar Arzani, was a court physician of Emperor Aurangzeb. He wrote Tibbe Akbari, and Mizan al-Tibb.

During the British rule, Eastern medicine in India declined. However the famous house of Hakim Sharif Khan of Dehli made a concerted effort to rejuvenate the decaying art of Unani medicine. Hakim Ajmal Khan founded the Hindustani Dawakhana and the Tibbiya College in Dehli. At the Tibbiya College, Dr Salimu-Zaman Siddiqui carried on chemical investigation of certain potent drugs and Ajmailain was produced. At Lucknow, the Talim al-Tibb college was established under the auspices of Hakim Abdul Aziz. Hakim Kabir al-Din was a distinguished author who wrote four books on Eastern system of medicine: Masaela Dauran-ey-Khoon, Sharah Qanoon Shaikh, Tashrih Kabir, Ilm al-Adwiyya and Burhan.

Muhammad Husayn al-Aqili al-Alavi, a practitioner and grandson of a well-known Indian practitioner wrote in 1732 Makhzan al-adwiyah dar-i bayan-i adwiya. The illuminated Persian manuscript, now at the National Library of Medicine, USA is in alphabetical order. At Lahore, Hakim Ghulam Nabi and Hakim Ghulam Jeelani promoted Eastern medicine by writing books such as: Tarikh al-Ittiba, and Makhzan al-Adwiyya. After the demise of Hakim Ajmal Khan, Hakim Abdul Majid (d.1922) started a pharmacy in 1906 which blossomed into Hamdard Waqf Laboratories. Hamdard now is a leading pharmaceutical house in India and Pakistan.

2.3.6. Zoology

Even as a dweller in caves and forests in the early Stone Age, man acquired considerable knowledge of animals, birds, fish, insects, and other creatures. As he gradually adopted a pastoral and agricultural life in the late Stone Age or early Bronze Age, several common species of these animals and birds were domesticated by him for the purposes of agriculture, transport, and food. The maintenance of domesticated animals necessitated a more thorough knowledge of their habits and needs. Thus, through observation, the acquaintance with animal life gradually became more systematic, leading to attempts at classification and the formulation of some basic concepts regarding the animal kingdom.

During the medieval period (A.D. 600-1700) the study of animal life made little progress, though a few works deserve consideration. The Bhavisya Purana (7th Century A.D), for instance, gives some fresh information about the life of snakes. It is stated that the mating season of naga (snakes) is the months of Jyaistha (May-June) and Asadha (June-July), and that the gestation period is the rainy months that follow. They lay about two hundred and forty eggs in the month of Karttika (October-November). Most of the eggs are eaten up by the parents. Those that are left, hatch in about a month or two. Eggs which arc of a golden hue produce male offspring, those of a somewhat paler colour and ail elongated ovoid shape female ones, and those of a different hue. After a week of their birth the young snakes turn dark; after a fortnight or three weeks their teeth and fangs appear. The venom reaches its maximum potency after twenty five days. The snakes shed their skin in six months. When snakes move on the ground, the folds of their skin on the under-surface alternately expand and contract, resulting in the projection and withdrawal of fine, filament-like legs, about two hundred and forty in number, the same as those of the joints on the skin. A venomous snake is said to live for a hundred and twenty years, but the life span of the non-venomous species is somewhat shorter, about seventy-five years.

In the Garuda Purana (A.D. 900) diseases of animals, particularly of horses and elephants, and their treatment have been described. The Salihotra by Bhoja (A.D. 1100) is another treatise of this period on diseases of horses and their treatment. The Asvavaidyaka by Jayadattasuri (A.D. 600) is a comprehensive treatise on the same subject. Dallana in his Nibandha-sangraha, a commentary on the Suhuta-samhita, gives some precise and detailed descriptions of deer and birds based on their colour, habits of life, and other features. The sources of his information, however, are not mentioned. He also quotes from an ancient writer, Ladyayana, a system of classification of kitas (insects and reptiles). According to this classification, kitas are to be distinguished from one another by their peculiarities as follows: (i) dottings or markings, (ii) wings, (iii) pedal appendages, (iv) face with antennae or nippers, (v) claws, (vi) sharp-pointed hair or filaments, (vii) stingers in the tail, (viii) hymenopterous character, (ix) humming or other noise, (x) size, (xi) structure of the body, (xii) sexual organ, and (xiii) poison and its action on human bodies.

The Muslim rulers of India showed great interest in animals and their habits and modes of life as well as in their ecological distribution in and around the country. Considerable information on animal life is recorded in the memoirs of Babur and Jahangir as well as in the Ain-i-Akbari of Abu'l-Fazl, the court historian of Akbar. Abu'l-Fazl mentions silkworms and certain animals of which no earlier record is known. These include a species of tailless ape (orangutan) found in Bengal, a species of deer with two tusks but without horns occurring in the Kumaon hills (probably musk deer), and civet cat which emits a fragrance of which the Mogul emperors were particularly fond. Jahangir, who was a lover of animals, contributed notably to the study of zoology. He made minute observations of their habits, behaviour, ecology, geographical distribution, and anatomy. He maintained a large menagerie and aviary which enabled him to study in detail the various animals kept there. He often dissected animals to verify popular notions about their anatomy. Among his original contributions are his studies of the sarus crane and the gestation period of the elephant. He is said to have made some experiments on hybridization between the ibex and the Barbary goat.

2.3.7. Conclusion

There was a considerable change in the education system. The Arabic system was introduced in a big way. Madrasas and Maktabs were established all over. The rulers tried to introduce reforms. Several works were written in the fields of Mathematics, Chemistry, Biology, Astronomy and Medicine. Most of the scientific works in this period were commentaries or expositions of the earlier treatises. Several important scientific works in astronomy, medicine and other sciences were rendered from Sanskrit to Persian/Arabic and from Persian/Arabic to Sanskrit. All round development was noticed in the sphere of mathematics, astronomy, medicine, chemical sciences and other natural sciences during medieval period of Indian history.

2.3.8. Summary

- *During the medieval period, Science and Technology in India developed two facets: one concerned with the already chartered course of earlier traditions and other with the new influences which came up as a result of Islamic and European impact.*
- *In mathematics, most of the available Sanskrit literature was translated during the Muslim rule of India, and in some instances Muslims made significant contributions. Euclid's Elements was translated into Arabic by Allama Nasiruddin Tusi, while Qutub al-Din Sherazi had translated it in 1311 into Persian.*
- *During the early medieval period Between the great astronomer and mathematicians Brahmagupta and that of Bhaskara II, in Indian subcontinent host of intellectuals like Govindasvamin, Sankaranarayana, Aiyabhata II, Sripati, and Satananda flourished. They with their work created an intellectual atmosphere for the growth of astronomy in India.*
- *South India played an important role during this period in cultivation of astronomy.*
- *Maharajah Sawai Jai Singh was an astronomer of the first order. He had some Greek works on mathematics (including Euclid) translated into Sanskrit as well as more recent European works on trigonometry, logarithms and Arabic texts on astronomy.*
- *Mughal metallurgists pioneered the method of wax casting while producing these seamless globes. Astrolabe used for astronomical observations was developed and improved upon in India.*
- *The instruments and observational techniques used at the Mughal observatories were mainly derived from the Islamic tradition, and the computational techniques from the Hindu tradition.*

- *Chemistry in medieval India was closely associated with alchemy which was an integral part of the Tantric cult. The alchemical ideas and treatises of India found their way to China and Tibet.*
- *There is plenty of evidence of the application of chemical knowledge and processes in the medieval period, particularly relating to metallurgy and metal-working, gunpowder, saltpeter, mineral acids, alum, paper, ink, soap, and cosmetics.*
- *It was during the medieval age Indian medicinal science dominated earlier by Ayurveda , was witnessed severe changes. Even Ayurveda also changed its course. New medical practices such as Unani arrived in India by the Arabian. The Arabian influence bring changes in medical practice, primacy and pharmacology.*
- *During the medieval period the study of animal life made little progress. The Muslim rulers of India showed great interest in animals and their habits and modes of life as well as in their ecological distribution in and around the country.*

2.3.9. Exercise

- Discuss the growth of astronomy in India from 8th to 18th century with special reference to astronomer, instrument and observation technology.
- Write an essay on the growth of Mathematics in the medieval period of Indian history.
- Give an account on the contribution of Sawai Raja Jai Sing for the growth of astronomy in Medieval India.
- How chemical science was flourished in medieval India? Discuss.
- Write an essay on the medical science, scientist and pharmacology of medieval India.

2.3.10. Further Reading

- Chanda, Tara., Influence of Islam on Indian Culture, Lahore, 1979.
- Elgood, C., Medicine in India, New York, 1934.
- Ashri, S.B., Delhi's Jantar Mantar Observatory, New Delhi, 2005
- Volwahsen, Andreas., Cosmic Architecture of India, Astronomical Monuments of Jai Singh, London, 2001.
- Bhatnagar, V.S., Life and times of Sawai Jai Singh, Delhi, 1974.
- Al-Hasan, A.Y., Science & Technology in Islam, UNESCO, 2001.
- Mukhopadhyaya , G. N., History o f Indian Medicine (3 Vols.). Calcutta University, 1923.
- Jaggi, O. P., *Science and Technology in Medieval India.* Atma Ram & Sons, Delhi, 1977.
- Taton , Rene (Ed.), History of Science: Ancient Medieval Science from the Beginnings to 1450. Translation, Thames & Hudson, London, 1963.
- Khareohat , M . P., Astrolabes (M . P. Khareghat Memorial, Vol. II, edited by D. D. Kapadia). Bombay, 1950.

*****

Unit-II

Chapter-3

INNOVATIONS IN THE FIELD OF AGRICULTURE

New Crops Introduced, New Techniques of Irrigation etc.

Structure

2.3.0. Objectives

In this lesson, students investigate the condition of agriculture in medieval India.. After completing this chapter, the learners will be able to:

- *to trace the growth of agricultural sciences in medieval India;.*
- *to understand the crop pattern practices during the period under discussion;*
- *to trace the origin and growth of new irrigational technology introduced during the medieval age of Indian sub-continent.*
- *to study the significance of agriculture in medieval Indian socio-economic setup.*

2.3.1. Introduction

Agriculture came to be practised when man gave up his nomadic habits and settled in favourable climate and topography. Although it has not been ascertained when the early inhabitants of India took to farming as their chief occupation, the practice of agriculture has been traced back to the Indus valley civilization. Thus, for at least the last 4,500 years the Indian society has been primarily an agricultural one. The variety of topography and climate of the subcontinent has afforded a great diversity in the crops cultivated in different regions. Moreover, the country possesses vast arable land. Indeed, India's agricultural wealth in terms of variety and production has significantly influenced the course of her history. Although farming methods in the medieval period remained much the same as before, considerable progress was made in the introduction of new crops and the improvement of some old ones. This chapter will discuss the status of agriculture during the medieval period of Indian history.

2.3.2. Significance of Agriculture in Medieval India

Medieval India, is known for its economic infrastructure and innovations in the area of agricultural produce. The crops of medieval India formed the major part of the economic setup of the India in those times. The crops included the food crops, non-food crops, fruits, etc. The crops production formed the basis of the export of India and also the increase in the financial assessment. India being an agricultural country since time immemorial the economy naturally depended on the crop production. The medieval rulers in India tried to improve the quality of the crops produce and for this the rulers improved the irrigation facilities. Indian soil in those times were rich in manures and little bit of manuring and tilling enhanced the crop produce. The Mughal rulers tried to improve the means of irrigation, supplying of improved seeds, solving cattle problems, and facilities of transport to increase the crop productivity. The crop production led to the strong establishment of sound land revenue system and thus made the medieval rulers established a strong army and large empires. During the medieval period, India, was introduced to new crops which led to the enhancement of exports and thus it affected the medieval exchequer. The following paragphas of this chapters throw lights on the status of agriculture in medieval India.

2.3.3. Condition of Agriculture

The Medieval India had a vast area of land cultivated by peasants residing in this geographical area. The European travellers who came to India in this period describes that the Indian peasants followed similar methods in agricultural production similar to that of their in Europe. The agricultural technology owned up by the peasants in India were no less inferior than the technology used by peasants in other parts of the world. The peasants cultivated the traditional crops but when they were exposed to the new crops they produced it with the same zest and zeal. Abul Fazl says that during Akbar rule ,in each locality as many as 41 crops were cultivated in a year. The method of agricultural production since ancient times has not been static and it has changed according to the needs of times. The Tughlaq rulers tried to improve the agricultural production by introducing the irrigation facilities. Firuz Shah Tughlaq by introducing new canals, new fruits and building fruit orchards led to the increase in the fruit production. Similarly, the Mughal rulers also tried to increase the agricultural productivity. The crops its cultivation , assessment and production brought about enhancement in the land revenue.

2.3.3.1. Crop Pattern

The soil of India helped the peasants in growing various types of crops and the agricultural technology, irrigation facilities, manures, seeds helped in introducing new crops also. Various varieties of some crops such as wheat, rice, sugarcane, indigo, etc, were grown which led to profits for the government and its assessment led to the enhanced productivity. The medieval Indian peasants produced a variety of food crops, cash crops, vegetables and spices. They were familiar with various advanced techniques of crop cultivation of their times viz., double cropping, three crops harvesting, crop rotation, use of manures and range of devices for irrigation etc.

2.3.3.2. Food crops:

The principal food crops produced were rice, wheat, barley, millet (jowar,'bajra) and a variety of pulses such as gram, arhar, moong, moth, urd, khisari etc.

Wheat: Wheat was one of the primary crops grown during the medieval period. Wheat was mainly grown in the regions of Agra, Allahabad, Oudh, Delhi, Lahore, Multan, Malwa, Ajmer, Kabul and Qandhar Sarkar. Kabul and Qandhar were known for especial varieties of crops. Kabul wheat was black in colour and on the other hand Qandhar wheat was extremely white in colour. Wheat in those days was also was a spring crop. Wheat had the greatest comparative value amongst the food grains similar to that of present date. The wheat cultivation was done in the regions having 20-25 cm. of rainfall, a temperature of 40 degrees at the time of sprouting and gradually 60 degrees at the time of ripening. Wheat cannot be grown in the regions of high rainfall. Sir Thomas Roe who visited India during the reign of Jahangir once met near Berampur 10,000 bullocks loaded with wheat. The province of Thatta also abounded in wheat during the reign of Shahjahan and Auragnjeb. Wheat has the greatest comparative value amongst the food grains as at present.

Rice: Next to wheat, another important crops of the medieval period was rice. For its successful cultivation plenty of water and high temperature was required. Abul Fazl says " if a single grain of each kind was collected, they would fill the vase. The harvests are always abundant, measurement is not always insisted upon and the revenue demands are determined by the estimates of the crop. The chief varieties are Kur, Shali, .The superior quality i.e., the shali rice ripens quickly, is pleasant to taste and smells fragrantly. It is harvested in Shrawani i.e., July, August. Munji rice was highly priced. It was chiefly grown in Agra province. In Khandesh fine quality of rice was produced. Bernier has described in his journey from Surat to Agra, Navapura that it grew good rice irrigated from a river nearby. The grain of this rice is half of the other quality. It smells as musk and is white and that all the grandees of India eat it and send it to Persia for presentation. The rice quality of Lahore was even better that of Bengal. Thatta was also an important centre for rice production. Travenier describes about the growth of rice in southern India. On his way from Surat to Broach, he found rice fields. He met women rice sellers in Ootockmond. He says that an oxen back in Persia they load 300 to 350 lbs of cargo …. Ten to Twelve thousand oxen at a time laden with rice, corn, and salt …Bernier says that Bengal rice is carried upto Ganges as far as Patna, exported by sea to Masulipatnam and to many other ports of Coramondal. It is also sent to foreign Kingdoms principality to the islands of Ceylon and the Maldives.

The Mughal kings tried to regulate the prices of important foodgrains. To control the rise in price of rice Aurangzeb by a definite farman prohibited the export of rice from the province of Gujarat.

Millet: Millets was one of the cheapest grains and grew in the regions of poor soil and deficient rainfall. Jowar was grown in the regions of Malwa, Gujarat, Ajmer, Delhi, Lahore, Agra, Allahabad and Multan. Millets were grown in the regions from Surat and Broach. The drier parts of Rajputana , West Punjab and West doab. Jowar were especially grown in the areas of Lahore and Khulasat in Allahabad.In Kotah (Rajasthan) gram were sold at the rate of Rs. 8 per mani (one mani was equal to 12 mds. Of 40 seers each) in village Mandania, 5 miles east of the bank of the river Chandoli.

Pulses: Pulses also formed one of the major parts of the food of the people of Medieval India. Pulses were mostly grown in Bihar, Doab, Allahabad, Oudh, Lahore , Multan and Malwa. A tribe called Manori tribe, was engaged in the transport of pulses in the Deccan. The chief pulses grown were moong, moth, mash etc. in the autumn harvests. In medieval times also for the vegetarian people pulses formed a rich source of protein. Their prices in the first years of cultivation were 48 dams per mound in all the provinces. In Agra, the price ranged from 48 to 13 dams per mound of moth; 22-48 for mash and 26 to 48 for mung.

2.3.3.3. Cash crops:

Sugarcane, cotton, indigo (used to extract blue dye), opium, silk etc. were some of the prominent cash crops of medieval India. Making of wine from sugarcane became widespread by the fourteenth century. During the Mughal period, sugarcane was the most widely grown cash crop with Bengal producing the finest quality. In this period, Bayana (near Agra) and Sarkhej (near Ahmedabad) produced the best quality Indigo. Sericulture (rearing of silk worms on mulberry plant), which was practised on a modest scale till the Sultanate period, became widespread during the Mughal period. Bengal emerged as the main region of silk production. The Mughal provinces of Bihar and Malwa produced the finest quality of opium. Tobacco cultivation was introduced in India by the Portuguese during the sixteenth century and it became widespread in the subsequent period. Surat and Bihar emerged as major tobacco producing centres. Similarly, from the seventeenth century, cultivation of coffee began on a large scale.

Indigo: Indigo also called Morinda- tinotoria formed one of the special crops of medieval period. William Finch has described the manufacture of indigo fully. He says it grows upto a yard and its stalk in the third year is no more than a man‟s thumb. The herb is sown once every three years. In the months of August and September just after the rains, the leaves are cut and gathered, cast into long cisterns , pressed down with stones and left therein with water. In the first year of its growth, the leaves are tender and not having attained perfection , produce heavy reddish "Neel". In the second year it is called Cattled (Khuntizal or Khuntri) . It is blackish" Neel". If the rain falls, it loose its colour and gloss and is called aliad (ala or moist) …..four things are required in the "nill" a pure grain, a violet colour, its glosse in the sunne and that it be dry and light, so that swimming in the water, or burning in the fire, is cast forth a pure light vapour, leaving a few ashes. The chief provinces engaged in the cultivation were Oudh, Agra, Multan. Malwa, Allahabad, Gujarat, Delhi. The chief regions engaged in the cultivation were Gangetic plain, the Indus plain and Gujarat. Indigo was sent by land from Agra to the Cambay ports or across the Frontier to Persia. Indigo during Akbar time was more costly than wheat. The indigo of Bengal was coming into prominence. The usual weight of a bale was about 220 lbs. for Biana and 150 lbs. for Sarkhej The effect of Dutch and English purchases was to extend the production of indigo. During the reign of Shahjahan in the district of Ahmedabad indigo was produced though in its quality it was inferior. The excellence of Khanwa's indigo was due to heavy soil and brackish water, the indigo is easily broken to that of grown in places where water is sweet. From Biana indigo is exported to Europe. During the reign of Aurangzeb indigo was largely exported from Bengal. The cotton clothes were sent from their places of origin to Central spots for washing such as Agra, Ahmedabad, Masulipattnam and certain places in Bengal , probably Dacca and Qassimbazar.

Sugarcane: Sugarcane was a rich source of sugar in medieval times. It grows well in tropical season requiring abundant heat and exceedingly moist soil. The juice obtained from sugarcane by crushing it in between the heavy rollers and the sugar is then obtained by evaporation and crystallization. During Akbar rule Bengal was first in sugar production. Abul Fazl says that two kinds of sugarcane; paunda and ordinary was grown in the regions of Agra, Allahabad, Oudh, Delhi, Lahore, Multan, Malwa and Ajmer. Sugar in large quantities was supplied to Golconda, Karnatic and also to Arabia and Mesopotamia through the towns of Mokhand, Basra and even Persia. The sugarcane grown in Aurangabad province was so juicy that 5 seers of juice could be formed. India's sugar under the reign of Jahangir was of three types; candy, powered and jiggery as at present. Candy was exported to England by the factory from Surat. In 1639 the Dutch merchants exported Bengal sugar from Masullipatan and in the forties the export trade to Batavia was nearly 5 lakhs of pounds.

Cotton: Cotton was in the black soil regions of Malwa plateau and Peninsula India. Cotton grows in sub- tropical climate with moderate and regular heat, bright sunshine was good but not excessive rainfall, a soil in which lime is present and the soil is saline. The long stapled cotton of North America was introduced during last centuries of British rule. Raw cotton was exported to Persian gulf and Arabia. Khandesh and Berar were the chief centres of cotton. Cotton, an autumn harvest was grown in the provinces of Agra, Allahabad, Oudh, Delhi, Lahore, Multan, and Malwa. The price of cotton was nearly 50 percent higher than that of wheat. Cotton was also exported to Burma, Malacca, Arabia and the east coast of Africa The demand of cotton yarn was increasing day by day. The chief centres were Navapoura, 104 miles from Surat, a great town for weavers . The cities involved in cotton manufactures were Cambay, Broach, Sironj, Calicut, Lahore, Agra and Ahmedabad.

Opium: Opium was manufactured from poppy seeds. Its cultivation required finest soil and the fields and proper weeding and watering was also required. The seed was sown in November and harvested in February and March. The poppy heads were cut out and scratched with a sharp instrument and a milky juice excluded which became brown in colour and after constant exposure to the sun and air is carefully collected by the farmer . The important centres of its production was Patna, Bihar, Malwa, Berar, Ghazipur and Khandesh. The Rajputs and Mughals used to eat it as an intoxicant and also used it as medicine. Opium was exported to Pegu, Java, Malaya peninnisula , China, Persia and Arabia. The Khandesh opium was exported through Surat and Bihar opium through Bengal.

Tobacco: Tobacco was introduced to India during the reign of Akbar by the Portuguese. It was first established in Gujarat where the leaf was first obtainable in 1613 . The Portuguese and the Dutch grew it in their colonies. Jahangir prohibited smoking in 1617 A.D. In the later part of Jahangir reign and during the reign of Shahjahan no restriction was imposed and tobacco trade flourished . Aurangzeb by a Farman in the 6th year of his reign, passed orders for the remissions of all custom dues on many commodities including tobacco and all the road taxes. Aurangzeb discouraged the production tobacco. Burhanpur and Bengal produced huge quantities of tobacco. Tobacco was exported to Arakan and Pegu.

2.3.3.4. Spices:

Spices formed the major part of the crops of the medieval India. Cardamom, ginger, pepper, nutmegs, cloves and cinnamon were the major spices. Cardamom was grown in Bijapur and ginger in the whole of Mughal dominion. Travenier says that cardamom was the favourite spice of the princes and it was priced between 100 to 110 rials. Ginger was brought from Ahmedabad. Pepper was brought from Bijapur Hollanders bought pepper from Malabar Other spices of note during this period are cuminseed, turmeric, coriander, cloves etc. By the Mughal period, the southern coast of India began exporting in large quantities different kinds of spices to various regions in Asia and Europe.

Saffron produced in Kashmir was we can say a special crop of medieval period. Pampur, south of Srinagar , in the districts of Maharaj, was famous for saffron cultivation where it was extended for 12 kos. The other place was Paraspur pargana near Indrokol , not far from Kamraj , where the cultivation extended to one kos. The main use of the saffron was in coloring clothes and dishes.

2.3.3.5. Fruits and Vegetables:

Fruit crop cultivation developed rapidly during the medieval period. Some of the Delhi sultans actively promoted growing of fruit crops. Firuz Shah Tughlaq, for instance, laid down 1200 orchards in the vicinity of Delhi. Mughal emperors and their nobles also planted lavish orchards. During the course of the sixteenth and seventeenth centuries, a number of fruits were introduced in India through outside agencies. The Portuguese for instance, introduced pineapple, papaya and cashew nut; etc. Cherry was brought from Kabul. Leechi and guava were also introduced during this period. A wide range of vegetables were also produced by the medieval Indian peasants. Abul FazI, in his Ain-i-Akbari, gives a list of vegetables which were, in use at that time. Potato, Chilies and tomato were introduced during the late medieval period.

Vegetables such as spinach, turnip, kachnar, chaulai, bethuwa, ginger, boi, peas, garlic, onion, carrot, radish, onion, carrot, radish, lettuce, sweet potato, lemon and numerous other varieties also produced during this period. These were grown in Agra, Allahabad, Delhi, Lahore, Malwa, Bengal, Bihar, Multan, Khandesh .Potatoes were introduced by Portugese and spread rapidly prior to that of Jahangir reign.

2.3.3.6. New Crops

Although farming methods in the medieval period remained much the same as before, considerable progress was made in the introduction of new crops and the improvement of some old ones. One of the important new crops was the cashew introduced from South America in the sixteenth century. The cashew has subsequently proved to be a valuable cash crop. Other crops introduced were the pineapple, potato, guava, and custard apple. Tobacco, papaya, and a variety of chilli first appeared in India at this time also. Coffee was introduced in India probably soon after Akbar's time (1556-1605). The yield from the cotton crop seems to have increased to a great extent in the thirteenth and fourteenth centuries. The Italian traveller Marco Polo speaks of extensive cotton cultivation in India. Pepper, ginger, and indigo were also widely cultivated. The Jesuits of Goa introduced systematic mango grafting in the late sixteenth century which greatly improved the quality of the fruit.

The Mughal emperors introduced new crops and cultivation. Musk- melon, water melon, apple, grapes, orange, guava, pomegranate, mango, date, fig, apricot, banana, pineapple, pear, various varieties of berries, and "singharas" were grown in many parts of the country especially in Kashmir, and in the *subah* of Lahore, Delhi, Agra, Allahabad, Awadh, Bengal, Bihar, Malwa, Multan and Ajmer. Jahangir introduced the cultivation of pineapples and several other varieties of grapes. Guava and Custard apple were introduced by the Portuguese. The honey drew variety of melon was cultivated in the northern plains. Muhammad Rida of Khurasan raised the first crop of melon and was honoured by Shahjahan. Abul Fazl says " The horticulturists of Iraq and Turan have settled here and the cultivation of trees is in a very flourishing state. Melons, water melons, peaches, almonds, pistachios, pomegranates, etc. are every here to be found Ever since the conquest of Kabul, Qandhar, and Kashmir , loads of fruits are imported; throughout the whole year the stores of the sellers are full and bazaars are well supplied. Musk melon come into Hindustan in Feb-March and are plenty in March-April. They are delicious tender, opening, sweet smelling specially the kinds called Nashparti , babashaykhi alshiri, alcha etc. Various kinds of grapes are to be had in May to July whilst the markets are stocked with Kashmir grapes during August-September. Varieties of fruits like grapes, melons, mangoes, peaches, apricots were grown in the provinces of Allahabad, Malwa and Kabul.

Jahangir was the Mughal emperor who built gardens in Kashmir and Lahore. Gardens were important part of the monuments of Mughal gardens. The flowers grown during the Delhi sultanate period continued to be grown during the Mughal period. Babur introduced a quality of rose of Gwalior to be grown in the gardens of Agra. Various types of flowers were grown during the Mughal period.

2.3.3.7. Conclusion

We find that the medieval era was a period of innovations in the area of crop production and techniques used. The water resources and the added means of irrigation, canals and technological use of implements and modes of irrigation led to the increase in crop production. It formed the basis of the agricultural production and was directly related to the economic infrastructure. The export of crops of high quality was done and it led to the enhancement of the revenue and thus brought a boost to the economic infrastructure of the medieval times.

2.3.4. Irrigational Development in India during Medieval Period

Early Indian agriculture depended on irrigation and natural rain. In fact, agriculture to a great extent depends on irrigation. It is no wonder that among all agricultural technologies maximum focus is given to the adequate usage of the hydraulic endowments. A lot of primary source of information as well as secondary data inform us a great deal of idea about the irrigation technology in Medieval India. Irrigation is the artificial application of water to soil, to cultivate land for the regular and consistent production of crops, which may broadly be categorized into two i.e. natural irrigation and artificial irrigation. Natural irrigation is through monsoon rains, which feed river bodies and become a good source of irrigation. Even otherwise, sprinkling of water over agricultural fields during rain is great irrigational tool. Artificial irrigation is through human efforts like digging up of wells, canals, hydraulic engineering efforts etc. Digging of wells and tanks has been propagated in India as a charitable work of merit. Due to unpredictable natural means of irrigation, agricultural expansion and the consequent evolution of human civilization has been critically related to the availability of sufficient hydraulic resources. Hence, it is not surprising that during the medieval period of Indian history maximum attention was paid towards the adequate usage of the hydraulic endowments.

2.3.4.1. Irrigation in Medieval India: Textual Reference

The Aparajitapraccha, a twelfth century work, seems to be the earliest text to devote a full chapter to the discussion of step wells, wells, ponds etc. The early medieval text Brihatkalpasutrabhashya shows a remarkable awareness of the variability of hydraulic endowments and hence we find the multiplicity of storage systems and irrigation mechanisms in disparate regions. It shows us the dependence of Lata (southern Gujarat) entirely on rain, of Sindhu (lower Indus valley and the Indus delta) on rivers, of the Dravida country (far south India) on reservoirs, and of Uttarapatha (generally north India) on wells. Kamandaka also emphasies the importance of irrigation for agricultural expansion. He advices the king to pay proper attention for providing irrigational facilities in case of failure of rainfall for the fertility of land leading to great agricultural production.

In large part of northern India rainfall pattern was not equal and regular so the only option left with Indian peasants was to supplement the rainfall by digging wells and censer it by tanks and storage reservoirs. The variation in rainfall pattern is also attested by Alberuni. As India's material culture is rooted in agriculture, the agrarian sector in turn is inseparably linked with irrigational devices and technology. Consequently, great magnitude was shown towards the improvement of the resources of irrigation. Aparajitapraccha presented a picture of havoc and distress caused by famines and suggested to improve the means of irrigation to escape their horrible consequences. Tanks, canals, river, wells etc. were the usual means of irrigation. Medhatithi stressed on irrigated agriculture to save the crops from the vagaries of monsoon.

Various primary source pays significant attention to the interrelationship between rainfall and agriculture. Parashara proposes to ascertain the amount of rainfall with the help of rain gauge which could give idea about the necessity of artificial means of irrigation. He also directs the people by stating that "All agriculture has rainfall at its roots, life too has rainfall as its source. Therefore, at the outset, acquire knowledge of rainfall very carefully." Rain water was the only dependable source of irrigation. Knowledge of rainfall is therefore a primary need of agriculture.

Rainfall which was earlier viewed as a phenomenon of fight between good and evil forces of nature, as a divine grace, was for the first time viewed as a subject of systematic study. In this context, excavation of wells (kupa), tanks (tadaga) and step wells (vapi) was considered meritorious and this too must have helped to ensure the easy supply of water for irrigation purposes. A Lekhapaddhati document also mentions kupa (well), tadaga (tank) and nadi (river) as usual means of irrigation. The reference to damming of water, reservoir bound with stones having resemblance to the ocean and the cultivation of sugarcane in the arid zone of Rajasthan also suggest harnessing of water for irrigation. The Aparajitapracha provides an elaborate description of wells which are classified under the following ten categories : (i) srimukhah (caturhastah), (2) vijayah (panchahastakah), (3) prantah (sadabhihostah), (4) dundubhih (saptahastakah), (5) manoharah (astahastakah), (6) cudamanih (saptahastakah), (7) digbhadra (dasahastakah), (8) jayah (ekadasakarah), (9) nandah (dvadasakarah), (10) sankarah (trayodasakarah). Kupikas or wells, are divided into two classes. Similarly, there is a reference of four types of kundas and six types of tanks. The reference of tanks, wells, canals and rivers is also found in Sukraniti. Such references lead to the inevitable conclusion that farmers of the time used varied means of irrigation to cope up with the sporadic nature of monsoon.

Since early times the primary responsibility to develop artificial means of irrigation was upon the king. Medhatithi states that it is the nature of rainy season that there should be rain, and yet, on account of the faulty action, either of the king or of the kingdom itself, there is sometimes drought. It was as a result of this notion that the kings undertook the excavations of wells, tanks and canals. The Aparajitpraccha advises that crops should be protected for maintaining the kingdom and that water reservoirs should be excavated for the irrigation of crops. It was the recognition of the practical importance of irrigational works which led

Lakshmidhara, the Gahadavala minister, to defy conventional notions class such works of public utility separately under dana (charity) and ascribe them a high spiritual efficacy. It was a change of real significance and the lead has been followed by subsequent writers on the subject. The Naradasmrti states that the erection of dyke in the middle of another man's field is not prohibited in view of the fact that it would be advantageous for irrigation purposes, while the loss is trifling. It also states that with owner's permission one can restore the decayed dyke.

2.3.4.2. Regional Trends of Water Management

It is not easy to assess the regional trends of water management of the period. Evidences make it a well established fact that due recognition was given to irrigation, both natural and artificial. The former channeled the water of the rivers and the monsoons in the northern and north-eastern parts of India respectively and the latter utilized the stored water in tanks, pools, and wells was adopted in central, north-western and southern parts of India.

North-Eastern India: At first the agricultural and hydraulic situation of northeast is to be studied. North-eastern India is plenteously watered by monsoons. Eastern India is also blessed with great rivers, such as the Ganges, the Brahmaputra and their tributaries. Settlement patterns in general were also based on irrigational activities and the available resources for it. One inscription from Bangladesh portrays the largest known brahmanical colonization program in north-India, planned and designed by a political authority consisting of an extensive settlement created in the tenth century in Srihatta (Sylhet area). It was a settlement of an impressive size, involving the merging of three districts, probably created out of virgin tracts (bhumicchidranyayena), as it had an extensive forest and marshy lands in descriptions on copper plates from seventh and eight centuries. This assorted arrangement was certainly sustained by agricultural resources obtained by bringing uncultivated tracts under the plough, possibly utilizing irrational resources. Varendri region corresponding to Rajashahi, Bogra and Dinajpur areas in modern Bangladesh, the very heartland of Pala dynasty (c. A.D. 750-1200) had been a flourishing, settled area for centuries. The royal inscription. This record mentions the cultivation of paddy and sesamum, a royal granary and well-planned, prosperous city of Pundranagara (Mahasthan in Bangladesh), the earliest known urban centre of Bengal and still an impressive archaeological site.

The region's prosperity continued in the Gupta age (fourth to sixth centuries) and during the reign of Sasanka (c. A.D. 600 to A.D. 619 if not up to A.D. 637). Varendra or Varendri, in the heartland of north Bengal, was described as the ancestral home (janakabhu) of the Pala kings patronage to irrigational works is also attested in north-east. Thus, Ramapala (1072-1127), the last great ruler of the dynasty and the champion of the eminent Sanskrit text, the Ramacharitam of Sandhyakaranandin is being endorsed not only for his conquests but also because of the public works of great utility in the form of the construction of large lakes with tall palm trees and lines of hillocks on their border, so as to make them look like veritable seas. These artificial water bodies built under the patronage of the king and his ministers were larger and more impressive than ordinary tanks (tadaga) and ponds (puskarini) and represent an augmentation of hydraulic resources. No less significant is the text's account of the levy of only mild taxes, obviously to ensure that the local human resources did not desert the war-torn territory. The eleventh-century charters from Bengal and Bihar contain regular references to rivers, streams (srotosvini), rivulets (ganginika), dikes (khata/kulya) and embankments (ali/brihadali). Besides Ramapala's efforts, there is little indication of the construction of large, supra-local hydraulic projects by political authorities in this region. However, it is evident that to ensure proper irrigation and drinking water facilities, Palas and Senas constructed large tanks throughout Bengal.

Kashmir Region: Considering the region of Kashmir, the uppermost and an important region of Northern India, the most outstanding irrigational project entailing inventive engineering skill belongs to King Avantivarman of Kashmir. Under his rule the minister Suyya dammed the river Vitasta (Jhelum) to save Kashmir from devastating floods of the Mahapadma Lake. Suyya deepened the bed of the Vitasta at its two ends, cleaned the river bed at its bottom after constructing a temporary stone dam at all threatened points and built protective stone embankments for seven yojanas along the river bank. Thus, he was able to shift the junction of the Vitasta and the Sindhu from old to its existing position. On the land raised from water he founded many villages protected by circular dykes and constructed extensive projects. Kalhana notices the prosperity resulting from the work and wrote verses in praise of the engineer. Another king of Kashmir, Lalitaditya Muktapida reclaimed many hitherto water-logged areas by making an arrangement at Laksadhara for conducting the water of Vitasta and by constructing a series of water-wheels, distributing it to various villages. Besides, king Harsha is credited for the excavation of the big Pampa Lake, identified by Stein with the modern Pampasar.

Ganga River valley: The greater part of Ganga River valley and the Ganga delta was watered by perennial rivers of glacial origin and well nourished by rains. Rock inscription at Ajayagarh fort situated between the entrances to the Patal Ganga and Patal Jamuna records the construction of a well by Kalyandevi, the chief queen of Viravarman, a ruler of the Chandella dynasty. The region including Bengal belonged to the category of devamatrika (area with profuse rainfall) and nadimatrika (riverine) tracts. Within this environment hydraulic resources and facilities were important landmarks of rural space.

Western India: The more arid western India, especially Rajasthan and Gujarat, famous for its agrarian economy featuring cereals and cash crops like cotton, oilseeds, indigo and sugarcane, is also very significant for the study of irrigational works. In Rajasthan, an area with less rainfall than Gujarat, inscriptions from the eleventh century onwards refer that the introduction of irrigational technologies resulted in the production of diverse crops even in arid environment. The Chalukyas of Gujarat had many important irrigational works to their credit. It seems that even the first king of the dynasty, Mularaja I paid due attention to the system of irrigation. Sridhara in his prashasti claims that one of his ancestors was appointed by Mularaja I (A.D. 941-996) to dig vapis, wells and tanks. A long list of efforts on the part of rulers to enhance the hydraulic resources can be prepared on the basis of available evidences. According to Merutunga, Durlabharaja (AD 1010-24) excavated a tank called Durlabha tank at Anahilavada. The queen of Bhima Chalukya (AD 1023-65) named Udayamati caused the construction of a new reservoir at Pattana which was better than even the Sahasralinga lake excavated by Siddharaja. She is also credited for the excavation of a well at Anahillapataka, which is now known as rani ki vav. The construction of two big reservoirs has been ascribed to Karnadeva (AD1066-94). The step well at Davad (near Idar) was probably built during his reign. Mayanalladevi, the mother of Jayasimha Siddharja (A.D. 1099-1144) is credited for the construction of a large number of tanks and vapis. Besides the usual local level irrigational projects like tanks and wells, vapis were also meant as irrigational resources.

Vapis began to figure prominently since the early medieval times. It has also wide distribution in the dry regions of Gujarat and Rajasthan and is the same as baoli of modern times. A more correct term for step well could be a staircase well or stepped well. In Gujarat, the terms vav or vavdi and in Rajasthan as well as other regions of northern India around Delhi and Agra the terms baoli or bauli were in common use. It is supposed that tanks at Viramgam and Dholka and stepwell at Nadiad and Virpur were built under the patronage of the mother of king Siddharaja. A water pond at Dohad and the step wells found along the major military and trade route from Anahilavada to Somnatha-pattana via Munjpura, Jhinjhuvada, Wadhwan, Dhandhalpura, Chobari, Gondal and Junagadh were built by Siddharaja. He also constructed a large reservoir called Sahasralinga Lake at his capital. Archaeology confirms the high engineering skill employed in this irrigational project. The lake received water from the river Saraswati with which it was connected by a 300 ft. long channel. Excavations have brought to light the stone sluices through which water was conducted to the lake. Further, during the reign of Bhimadeva II (A.D. 1178-1242) an effort seems to have been made to extend irrigational facilities to north-west Saurashtra and Kutch. Not only kings but also feudal lords and merchants showed great concern towards constructing vapis and providing other irrigational facilities.

Prabandhacintamani acknowledges Tejapala, the minister of king Viradhavala as the constructer of many tanks. The records of the period clearly point towards the digging of tanks and wells by many feudatories and ministers under the auspices of Kalachuris. Malayasimha, a feudatory is reported to have dug a tank in A.D. 1192. Rauta Vallaladevaka, another feudatory, dug out a water channel. Similarly, in the region of Raipur-Bilaspur area there are references of the excavation of tanks and wells by the Tummana Kalachuri feudatory Brahmadeva and ministers Purusottama and Gangadhara. Likewise, the Mangalana (Jodhpur) stone inscription (AD 1215), praises the mahamandalesvara Jayasimha for building a vapi in the land of water scarcity (daumara bhumi). An inscription found at Sunak, 14 miles southeast of Anahilavada, mentions the construction of a vapi by thakkura Mahadeva. The Ladol Copper plate inscription also (A.D. 1099) mentions that Siddharaja donated a piece of land for the maintenance of a vapi, constructed by Vilahala, the son of a mahamatya (minister) at Takaudhi, near Gambhu in north Gujarat. In the Gaya district of Bihar Gangadhara, a minister of King Rudramana is said to have constructed a tank. Wells (kupa), step wells (vapis), tanks (tadaga), reservoirs (sarah) and watering troughs (prapa) have been constructed by Vastupala, a merchant minister at a number of places in Gujarat. There are several other references where kings and merchants, ministers and feudal lords took keen interest in providing the irrigational facilities in north India during early medieval period. The state evinced keen interest in the upkeep of the irrigational works and even framed rules for their proper functioning. While recently scholars are realizing that the existing sources mostly indicate the preponderance of small scale local level irrigational projects. However, there are also some instances of large scale or supra local irrigation projects. Lekhapaddhati documents also mention the varigriha karana (official in charge of irrigation). It suggests that there was a department of irrigation and state took interest in irrigation work.

Besides the above mentioned irrigational works which owed their construction to the state, there must have been many others built by private individuals. It may be regarded that the individual and group initiatives in launching and maintaining irrigational projects far outnumber those of royal or administrative efforts.

As regards the technical devices used to raise water from wells our evidences are also not lacking. Desinamamala refers to such terms as agatti, unkaddi and dhenka which according to the editor of text, mean a contrivance for drawing water in which a horizontal beam with a bucket hanged on the one end see saw on a vertical post. This contrivance was operated probably by foot and could be used in wells and tanks where water was not deep. Bana refers about the irrigation of paddy fields through ghati. Merutunga also notices the use of water-wheel for irrigating the fields. By describing the rotation of water-wheel, he states "the empty buckets became full and the full buckets empty." However, the whole technique of drawing out the water has not been described by him. But, it is apparent from one metaphorical reference that araghatta or water-wheel in the region of Gujarat was used to draw out the water from deep wells.

Inscriptions of southern Rajasthan especially from the regions of Jodhpur, Udaipur, Banswara, Sanchor and Sirohi repeatedly refer to irrigation with the help of arahatta or araghatta and dhimada or dhiku. The Pattanarayna inscription from Sirohi (AD 1287), specifying a levy on the produce of irrigated fields, enjoins that two seers should be paid from the field irrigated by dhimada and eight seers should be paid from that irrigated by an arahatta. This difference with regard to the levy of produce between dhimada and arahatta in terms of the methods of operation and their relative capacity to irrigate. The technical nature of arahatta, generally translated as a Persian wheel, is a matter of controversy. The device araghatta demands close scrutiny. The essential part of the araghatta was the ghatiyantra or the device with pitchers, usually mounted on the wheel, but not attached to its rim. The ghatiyantra as an irrigational device is therefore often held as a pot-garland. The Upamitibhavaprapanchakatha of Siddharshi (A.D.906) presents the most elaborate account of the device. The araghatta, according to the text, seems to have drawn water from a reservoir which in turn received its water from irrigation well. The text highlights the spokes (arakas) of wheel which was a revolving apparatus though it does not refer to any gearing mechanism enabling the conversion of the horizontal rotary motion into a vertical rotary motion. The latter feature which became visible from the fourteenth century onwards, represented the typical Persian wheel or the saqia. The prevalence of araghatta as a hydraulic machine is best demonstrated by an eleventh century panel from Mandsor (Pali district, Rajasthan).

South India: One may recall here once again the recognition of the regional variations in the hydraulic resources and projects in the vast subcontinent in the early medieval text, Brhatkalpabhasyasutra. The text in question impressed upon the importance of tanks as the principal hydraulic project, typically associated with the Dravida country, that is, the far south India, lying to the south of the river Krishna. The earliest Tamil poetry, the Sangam anthology, informs us of the five ecological divisions in ancient Tamilakam. These were neidal (agricultural tract), marudam (coastal area), kurrinji (forested mountainous area), mullai (pastoral zone), and palai (dry and arid tract). Until the fifth century A.D. settlements in Tamilakam were mostly situated in the coastal and agricultural tracts. It is only during the post-A.D. 600 days that permanent agrarian settlements spread outside the neidal and the marudam eco-zones. This became largely possible with the expansion of agriculture by issuing a large number of land grants, in other words, by local formation or the process from within. The expansion of agriculture is inseparably intertwined with the enlargement of the irrigated area. As the far south does not possess many rivers of perennial nature, the spread of irrigation agriculture in that region largely depended on tank irrigation. Though this was, in many cases, an initiative of the village community, there are known instances of support for tank irrigation at the rulers' level. A few illustrations on this point will be in order.

The Pallavas and the Cholas are particularly noted for excavating tanks of impressive size. Royal inscriptions describing the construction of these tanks by the rulers' initiative also inform us about the sluices which were indeed meant for regulating and distributing the water from the tanks to cultivated fields. The Tiryaneri tank had 23 sluices, while the Viraneri tank had as many as 74 sluices. Several sluices figure in the description of the Cholaganga tank in the Tiruvalangadu copper plate of Rajendra Chola. These channels, according to the inscriptions, were connected to irrigation channels. These sluices were dressed in granite slabs. The existence of many sluices, possibly of an impressive size, in the tanks, speaks of the large size of the tanks themselves and the substantial area irrigated by them.

The Vijaynagar Kingdom (1336-1546 A.D.) in the south took keen interest in building large and small storage tanks. Anantraj Sagar tank was built with a 1.37 km long earthen dam across the Maldevi river. The well-known Korangal dam was built under King Krishnadevraya. The Bahamani rulers (1388-1422 A.D.) introduced canal irrigation for the first time in the eastern provinces of the Deccan.

2.3.4.3. Means and Methods of Irrigation during Sultanate and Mughal Era

The Delhi Sultans, in particular, promoted canal irrigation. Ghiyassuddin Tughlaq (A.D 1320–1325) built a number of canals for this purpose. However, Firuz Shah Tughlaq laid the largest network of canals. Four such canals are frequently mentioned in contemporary sources. These were - (i) from Sutlej to Ghaggar, (ii) Opening from the Nandavi and Simur hills to Arasani, (iii) from Ghaggar, reaching upto the village to Hiransi Khera, and (iv) excavated from Yamuna and extended upto Firuzabad.

The tradition of Delhi Sultans to construct canals was continued by the Mughal emperors as well. The Nahr Faiz, for instance, built during Shahjahan's reign carried water from Yamuna and irrigated a large area. Irrigation system in Mughal India was quite developed and it was made possible by storing well water, surface water as well rain water. Water from these sources was stored in tanks and then distributed across the vast agricultural lands through a large network of canals. Further, some water-lifting devices were also used for utilising the stored water. During the Mughal rule, both in the Doab and Haryana region the role of canal irrigation became quite significant by the closing decades of the nineteenth century. It is further to the western province particularly in the Indus plains where the modern canal system brought about a vital change. One of the most important features of the irrigation system in Mughal India was the artificial irrigation system. It supplemented the natural bounty of the monsoons. The chief means employed for this purpose had been the construction of wells, tanks and canals.

Further, historical records show that in the Upper Gangetic plains wells were the principal sources of irrigation. Different methods were applied for drawing water out of the wells for irrigation purposes. Most of the wells were kachcha (not concreted). Those used to be dug afresh almost every year. Cultivation of crops depended mostly upon rainfall and only partly on wells. Thus, wells were considered important at that time.

It was also believed that in many tracts, especially in the central Ganga-Yamuna Doab, there was a heavy declination in the number of wells, owing to interference by modern canals with the natural drainage system of the country. Moreover, archaeological remains of the pre-colonial system of south Indian dams, tanks and canals testify to the great antiquity of irrigation tanks in peninsular India.

In cases where a river rises and inundates the fields seasonally every year, both the irrigation system and fertilisation were considered to be natural. The seasonal inundations of the rivers were almost uncontrolled; and nothing reveals their range more clearly than the spectacular changes in the river courses which used to take place from time to time. These changes particularly affected cultivation in larger areas. It was in northern India where some large canals were excavated during Mughal period. The Haryana tract was not served by any perennial river. Thus, the common practice in the region was to build dams across the streams for creating artificial inundation or for continuous supply of water for cultivation. Further, in the Punjab province, a small system of canals was brought into existence in the Upper Bari Doab. The common practice had been to either cut artificial channels from the river or canals to lift the water from the river or its branches for supporting agriculture. Thus, it becomes quite clear that irrigation system during Mughal rule was quite advanced supporting the core basis of economy.

2.3.5. Conclusion

Indian economy has always been agriculture centric, it was inseparably linked with irrigational devices and techniques. Literary as well as epigraphic sources of the period indicate that great magnitude was shown towards the improvement of the resources of irrigation and introduction of new crops in India. Besides the existing crops new crops were introduced in India. The royal household encourage production of new crops by providing technology such as irrigation. New irrigation resources like araghatta/arahata and vapi which were particularly suitable for lifting water from great depths; began to appear in the texts describing irrigational developments of the period. Araghatta, generally translated as a Persian wheel was much in use in early medieval northern India especially in arid regions of Gujarat and Rajasthan. There is little doubt that the introduction of araghatta and vapi considerably benefited agricultural production especially because these were mostly in use in the relatively arid western India. However, it seems quite probable that state's initiative as well as public efforts in providing and maintaining irrigational facilities led to profusion of multiple crops.

2.3.6. Summary

- *In the medieval period, the pattern of agricultural practices was more or less the same as that in early India. Some important changes occurred in the introduction of new crops, trees as well as horticultural plants by foreign traders.*
- *The principal crops were wheat, rice, barley, millets, pulses, oilseeds, cotton, sugar-cane and indigo.*
- *The Western Ghats continued to yield black pepper of good quality and Kashmir maintained its tradition for saffron and fruits. Ginger and cinnamon from Tamil Nadu, cardamom, sandalwood and coconut from Kerala, were becoming increasingly popular.*
- *Tobacco, chillies, potato, guava, custard apple, cashew and pineapple were the important plants which were introduced to India during the sixteenth and seventeenth centuries. It was during this period that the production of opium from poppy plants began in Malwa and Bihar regions.*
- *Improved horticultural methods were adopted with great success. The systematic mango-grafting was introduced by the Jesuits of Goa in the middle of sixteenth century.*
- *Imperial Mughal Gardens were suitable areas where extensive cultivation of fruit trees came up.*
- *For irrigation, wells, tanks, canals, rahat, charas and dhenkli charas (a sort of a bucket made of leather used to lift water with the help of yoked oxen) were used.*
- *Persian wheel was used in the Agra region. In the medieval period, agriculture was placed on a solid foundation by the State by introducing a system of land measurement and land classification, beneficial both to the rulers as well as the tillers.*

2.3.7. Exercise

- Discuss the condition of agriculture in the medieval period of Indian history.
- Write an essay on the crop pattern of the medieval period in Indian history.
- Examine the significance of agriculture in medieval Indian society and economy.
- Give an account on the regional variation of irrigation technology adopted in medieval period of Indian history.
- Discuss the new irrigation technology introduced in India during medieval period by the ruler for improvement of agriculture.

2.3.8. Further Reading

- Bose, D.M.. et.al. (ed.) A Concise History of Science in India, National Science Academy, New Delhi, 1971.
- Chakravarti, Ranbir., 'Agricultural Technology in Medieval India', The Medieval History Journal, Vol.11, No.2, July-December, 2008.
- Chakravarti, Ranbir., Exploring Early India, Macmillan Publishers, New Delhi, 2011, Second Revised Ed. 2013.
- Chattopadhayaya, B.D., The Making of Early Medieval India, Oxford University Press, Delhi, 1994.
- Chauhan, G.C., Economic History of Early Medieval Northern India, Atlantic Publishers and Distributers, New Delhi, 2003.
- Gopal, Lallanji, Aspects of Agriculture in Ancient India, Varanasi, 1980.
- Gopal, Lallanji., Economic Life of Northern India (A.D. 700-1200), Delhi, 1965. Second Revised Ed. Delhi, 1989.
- Mukhia, Harbans., 'Agricultural Technology in Medieval North India', Perspectives on Medieval History, New Delhi, 1993.
- Nene, Y.L.. Glimpses of Agricultural Heritage of India, Asian-Agri History Foundation, Andra Pradesh, 2007.
- Niyogi, Puspa., Agrarian and Fiscal Economy of Eastern India (From the 4th to the 12th Century A.D.), Kolkata,2010.

*****

Unit-3

Chapter-I

EARLY EUROPEAN SCIENTISTS IN COLONIAL INDIA

Surveyors, Botanists, Doctors, Under the Company's Service.

Structure

3.1.0. Objectives

In this lesson, students investigate introduction modern sciences in India by colonial masters. After studying this lesson you will be able to:

- *to learn the use of modern science by colonial master in India as a tool for colonization;*
- *to analyze the various European scientist and their work carried out during 18th & 19th century India;.*
- *to investigate development of various branch of natural sciences in colonial India.*
- *to trace the involvement of Indian natives in early scientific endeavor in India by European scientist and*
- *to study the impact of modern science in India upon Indian and their early response..*

3.1.1. Introduction

A major accomplishment of the Renaissance in Europe was the 1498 discovery of the direct sea route to India. The great commercial success of the Portuguese spurred the Dutch, the English, and then the French to venture out to the sea. The overseas trade was extremely profitable. The navigational needs of the traders acted as a great incentive for development of science in Europe. The best scientists of the time applied their minds to 'discover the longitude'. Maritime trade transformed not only European economy but also its state of mind. For the first time in history of mankind, production of wealth depended not upon the courtesy of God and the King, but on human endeavour. Merchants and artisans now became respectable and influential members of the society. And since the new rich class owed its wealth to science, it became patron of science. The new experiences weakened the hold of the past authorities. It was in this circumstances that the modern science came to India in tow with the Europeans. The very act of reaching India from Europe showed, a sense of adventure and competence. It was natural for these early visitors to try to acquaint themselves with their new environment, for survival as well as for profit. Early European scientific endeavours in India consisted of two disciplines, geography and botany.

3.1.2. Beginning of Modern Science in India

In the early days, the Europeans- were confined to the coastal areas and had no reason to venture into the interior. Geographical exploration therefore fell to the Jesuit priests. The Society of Jesus was set up in 1540. The first Jesuits arrived in India in 1542 and remained active for more than 200 years. In 1759 the King of Portugal banished all Jesuits from his colonies; and in 1773 the Pope banished the order altogether. It was revived in 1814, with the first English Jesuits arriving in Calcutta in 1833. The Jesuits had the time, scientific training and the opportunity of crisscrossing the country. Thus in 1580 Father Monserrate (1536-1600) on a mission to Emperor Akbar took observations for latitude from Surat to Fatehpur Sikri. The next year when Akbar marched to Kabul against his half-brother Mirza Hakim, he took Monserrate along as a tutor for his second son Murad, and for making observations on the way.

The Jesuits sent their observations and diaries to Europe where they were faithfully preserved and ignored. Europe was not yet ready for India. It is only in the 18th century when knowing India became a paying proposition that Jesuit data were dug up and put to use. The 34 volumes of Jesuit observations from all over the world published at Paris between 1702 and 1741 were avidly read by the colonialists, and a 26-volume edition appeared in 1780-83, of which six volumes were devoted to India.

While geography was left to the missionaries, botany did interest the traders. This is not surprising. After all, it was the lure of the culinary plant that had brought Europeans to India in the first place. But plants had other uses also. They provided drugs in the treatment of diseases and had in addition exotic value. It was only natural that visiting seamen should take interest in plants for reasons of their own health, and for their medicinal, commercial and curiosity value back home. The first western botanist in India was the Portuguese Garcia D'Orta (1479-1572), a physician and professor at Lisbon, who came to India in 1534 and stayed till his death. D'Orta, said to be a converted Jew, moved in 1538 or 1541 to the island of Bombay which the Portuguese had acquired in 1528 and which they now leased to D'Orta in perpetuity at an annual rent of £85.

Obviously D'Orta could not hold on to his estate, but in 1563 he wrote a book called Dialogues on Samples and Drugs. The next dabblers in botany were the Dutch, who opened a factory (a fortified warehouse) at Cochin in 1663. The material collected from Malabar was published at Amsterdam as 12-volume Hortus Malabaricus and illustrated by 794 plates 'some of which are so good that there is no difficulty in identifying them with the species which they are intended to represent.' Such work had a curiosity value, but fulfilled no pressing need, as can be seen more clearly from the work of Rumphius whose manuscript on the flora of Spice Island of Amboina completed in 1690 was published years later between the years 1741 and 1755. Another work with delayed but influential response was by Paul Hermann who spent seven years (1670-77) exploring the fauna of Ceylon at the expense of the Dutch company. Since this 600 species collection was sent to Europe, it was used by that great systematist Linnaes in 1747 to publish his Flora Zeylanica.

We have seen that the early use of modern science in India was sporadic and random, and motivated by localized curiosity. Most of it had no contemporaneous significance and was incorporated into the main body of science much later. Additionally, it left the Indians themselves untouched. Of far greater significance was the medical expertise of the British doctors. This expertise was sought by the Indian rulers who paid for it in terms of goodwill and trading concessions. Thus Gabriel Boughton, a surgeon on the East India Company's ship Hopewell, was sent to Emperor Shahjahan's court at Agra in 1645. He served between 1645 and 1650 as a surgeon to Shah Shuja, Emperor's second son and Viceroy of Bengal, from whom he got a farman for free trade issued in favour of the Company. Then in 1716, when the Company sent an embassy under John Surman to the Mughal Emperor Farrukhsiyar, it included a surgeon William Hamilton, who came in handy in curing the Emperor of a painful disease, which had delayed his marriage. The surgeon's skills brought the English party into high favour not only with the Emperor but also with his powerful Vazir. The embassy returned with three farmans confirming the right to trade free of all duties. Ironically, this gave Company as well as the traders a big advantage over their native competitors. Surman's embassy has been hailed as 'a landmark in the history of the Company's settlements'.

3.1.3. Growth of Science- An Instrument of Empire Building

With the post-Aurungzeb (1707) collapse of the Mughal Empire, India became available for grabs. The European *vaishya* outfits developed *kshatriya* ambitions. The 1757 battle of Plassey laid the foundation of the British colonial empire. Earlier scientific activity by the Europeans in India had been motivated by commerce and curiosity. Now science was pressed into the cause of empire-building and institutionalized. The chapter will discuss the advent and growth of modern science in India in two stages of development. The first stage, called 'the colonial-tool stage', consists of introduction and use of science, especially by the British, as an imperialist tool, with incidental benefits to science. The second stage, the 'peripheral native stage', came into being when the British were well entrenched in India. In it, the Indians were assigned the peripheral role of providing cheap labour to the colonial science machinery. We shall now discuss each stage separately, drawing illustrations mostly from the Survey of India which represented science in the most dedicated service of the state.

3.1.3.1. The Colonial-Tool Stage

3.1.3.2. Role of the Portuguese

The gold coins minted by the Portuguese for use in India depict the armillary sphere, the pre-telescopic basic navigational instrument used for determining the latitude. This was Portugal's way of paying tribute to science to which it owed its power. The Portuguese arrived in India even before the Mughals did. Their love for Christianity and hatred for Muhammadans far exceeded their desire for Indian territory. Moreover, given their small population they did not quite know how to successfully deal with the scurvy deaths on the sea. The Portuguese introduced navy as a parameter in India's geo-political equations, placing the Indian rulers at a disadvantage. Even when its power was at its peak, the Mughal Empire had to seek the help of the religiously neutral British to thwart the Portuguese attempts at preventing Indian Muslims from sailing to Mecca. When the Portuguese first arrived in India, Copernican heliocentrism had not yet made its appearance. But by the time the Mughal Empire collapsed, Europe was already on the verge of industrial revolution, so that science and colonialism could feed each other.

3.1.3.3. French Initiative

Filling the political vacuum in India required as a first step knowledge about its geography. The French were more successful on the scientific front than on the colonial. The first worthwhile map of India was compiled in 1752 by the French geographer Jean-Baptiste Bourguignon D'Anville at the request of French East India Company, who based it on Jesuit data and on whatever geographical information he could lay his hands on. The value of D'Anville's Carte de l'Inde can be judged from the fact that it was reprinted in England in 1754 and then again in 1759, along with the annotated translation of his memoirs

3.1.3.4. Rise of the British

Astronomy was the first modern science to be brought to India, as a geographical and navigational aid. Its early use was however sporadic and mostly out of personal curiosity. Systematic scientific effort became essential when the 1757 battle of Plassey transformed the British East India Company into a shareholder of Indian polity. The Company Bahadur was fully conscious of its needs: survey of its present and future lands; safety of navigation; increased revenue; and proper administration. The first need was geographical knowledge. In 1757 itself when Clive was still at the Nawab's capital Murshidabad, he proposed that 'an exact and useful survey may be made which will enable us to settle beneficial boundaries'. Accordingly a 'Surveyor of the New Lands' was appointed in 1761, and in 1767, two years after the Company received divani rights over Bengal, Bihar and Orissa, Maj. James Rennell was made the 'Surveyor-General of Bengal'. Rennell's Bengal and Behar Atlas appeared in 1779-81, and the Map of Hindoostan in 1782-92.

Surveys were continually required for military purposes. Geographical location of important places in the country was determined with alacrity by 'borrowing a sextant here, a watch there, and a quadrant in another quarter, from different officers at Calcutta who happened to possess them'. Surveyors were sent out with every army to prepare route maps.

The importance of 'military geography' can be gauged from the fact that in 1790 when the Governor General took the command against Tipu, the Sultan of Mysore, he appointed the Surveyor-General to his personal staff. In 1793 the Company paid the fabulous amount of Rs 6000 to a surveyor, Lt Robert Hyde Colebrooke, for a map of Mysore accompanied by a memoir Colebrooke served as Surveyor-General of Bengal in 1794-1808.

The Trigonometrical Society of India: The destruction of Tipu in 1799 extended the Company's territories from the east coast to the west. Just as Plassey had produced its Rennell, Seringapatam produced its Lambton, only more quickly. Unlike Rennell's survey which was run in traditional, route survey style, Maj. William Lambton (1753-1823) modelled his on the lines of the recently started surveys in France and England. The Trigonometrical Survey of Peninsular India was started in 1800 with second-hand instruments bought within the country. Expectedly, its history is also the history of the entrenchment of the British in India. In 1817 the Mahrattas were finally crushed. On 1st January 1818 the survey was renamed the Great Trigonometrical Survey of India (GTS) and extended to cover the whole country. It even surreptitiously covered trans-Himalayan region. The GTS came to its own in 1830 under Lt. Col. Sir George Everest (1790-1866) who was also appointed the Surveyor- General. The GTS fixed with great accuracy the longitude and latitude of a large number of places. The details were then filled in by the Topographical and Revenue Surveys. In 1878 the three were merged under the name Survey of India. Uniformly accurate data from such a huge landmass as India led to the important geodesical theory of isostasy by Archdeacon John Henry Pratt (1808-71) and to a mathematical model of the earth, known as Everest geoids.

As early as 1787, General William Roy, the founder of the British survey, wrote how desirable it was to determine the length of a degree of latitude on the Coromandel coast and in Bengal. It was too early for the Company to bother about the shape of the earth when its ships were getting wrecked. Rennell and Alexander Dalrymple, the Company's hydrographer at London, made a joint reply: 'Whatever advantage to science may be derived from the exact determination of the figure of the Earth, we conceive no other benefit can possibly attend the Admeasurements in Bengal; but that proposed on the Coast of Coromandel will contribute towards the construction of an exact chart of the Coast'.

Astronomical Observatory of Madras: The Coromandel coast is rocky and full of shoals and without a natural port and was a graveyard for the Company's ships. A survey of the coast was thus literally a matter of life and death, and eventually in 1785 a professionally trained surveyor-astronomer Michael Topping (1747-96) was brought from England, on free passage and equipped with his instruments. Since his work required a reference meridian, an Astronomical Observatory was set up at Madras in 1790. It was the first modern public observatory outside Europe. While pleading for it. Topping reminded the Company Directors that they now had a chance of 'affording their support to a science to which they are indebted for the sovereignty of a rich and extensive empire'.

Although the Company had grandiosely declared that the purpose of the Observatory was to 'promote the knowledge of astronomy, geography, and navigation in India', it was clear that the main aim was to promote the Company's profitability' Science was only a part of the duties of the Company's officers. In the early years, the Observatory was no more than a surveying outfit. This role ended with the 1830 reorganization of the GTS, but navigational need was still outstanding. Increased sea-trade activities of the British required familiarity with the southern skies. In 1844 after 14 years of labour, Thomas Glanville Taylor (1804-48) produced the celebrated Madras catalogue giving positions of about 11,000 southern stars. It was hailed by the Astronomer Royal as 'the greatest catalogue of modern times' and revised in 1893 with funds from the India Office and the Royal Society.

The Observatory was now redundant. Even the British astronomers who had now observatories in South Africa and Australia lost interest. The Astronomer Royal wanted it abolished but could not succeed against the assertion of the local British pride. Although the observatory was saved, but no new equipment was sanctioned. Fortunately, there were workshops of the Public Works Department that could maintain the ageing instruments. India's astronomical fortunes revived with the advent of the new field of solar physics. India was ideal for extensive photography of the sun, which was not possible in cloudy Britain. Also, it was then believed that a study of the sun will help predict the failure of the monsoons. In 1878 solar photography was started at Survey of India, Dehra Dun, and photographs were sent to England for analysis. A solar observatory was established by the Imperial Government at Kodaikanal in 1899 (which still exists).

Once the Trigonometrical Survey was begun, the Government lost interest in Madras Observatory. All surveys were manned by military officers. Whereas meteorological and magnetic observations were considered legitimate military duty, pure astronomy was not.

The last word on where pure science stood up visà- vis the applied belongs to the irrepressible Everest. In 1834, on orders from the Government, astronomical instruments from the Survey were issued to enable the former Bombay Astronomer to observe the phenomenon of the opposition of Mars. This happened when Everest was out on field tour. On his return Everest made a strong protest against the loan, saying: '... The discoveries which the late Astronomer of Bombay is likely to make in science would hardly repay the inconvenience occasioned by retarding the operations of the Great Trigonometrical Survey...'. It should however be noted that John Cumin, the first Director of the Colaba Observatory, was dismissed from service in 1828. From geography to geology was but a natural step. The survey of the Himalayan region naturally brought forth interest in its legendary mineral wealth. The company attached Mr Alexander Laidlaw 'Mineralogist and Investigator of Natural history' for the survey of Kumaun. The Governor-General wanted him to look for metals. Mr Laidlaw did not pay attention to any thing, and was dismissed after two years.

In 1818 Dr Henry Voysey a surgeon who doubled as a geologist was attached to the GTS so that he could draw 'attention to anything that might influence geometrical and astronomical observations'. Voysey's reports included one on the stone used in building the Taj at Agra. He also reported on diamond mines of South India. Industrial revolution meant the realization that coal was more important than diamond. As the steamer ships were pressed into use, the Government became interested in coal fields. This led to the appointment of a Geological Surveyor to the Company, and in 1851 to the Geological Survey of India. Geological evidence in support of the continental-drift hypothesis came from India; this fact is commemorated in the name 'Gondwana' for the ancient southern super-continent. The name, Gondwana System, was introduced in 1872 by Henry Benedict Medlicott (1829-1905), from 1854 professor of geology at Roorkee and later superintendent of the Geological Survey of India.

Early Botanical Study: Systematic study of botany in India was pioneered by John Gerald Koenig, a native of the Baltic province of Courland, who came to the Danish settlement at Tranquebar near Madras. Koenig was a pupil of the celebrated Linnaes and at once initiated many enthusiasts into botanical studies. The workers included Sir William Jones, the well-known oriental scholar, who in 1784 established Asiatic Society of Calcutta. Most workers were however content with collecting the samples and sending them to Europe. Rottler, a missionary, was the only member of the band who himself published in Europe descriptions of any of the new species of his own collecting; they appeared in Nova Acta Acad. Nat. Curiosorum at Berlin. All these efforts were individual.

A recognized centre for botanical activity was provided by the East India Company in July 1787 with the establishment of a 300-acre botanical garden at Sibpur on the bank of Hooghly, near Calcutta.

At the fall of Mysore, the botanical garden at Bangalore (the Lal Bagh) was appropriated by the Company 'as a depository for useful plants sent from different parts of the country'. The Company's botanist at Madras (Dr Benjamin Heyne) was ordered by the Governor-General to accompany the Surveyor.

An important task assigned to the colonial botanical gardens was dealing with malaria, the scourge of the tropics and the biggest obstacle to colonial expansion. The bark of the cinchona tree as a cure for malaria was introduced in Europe from South America in 1640 by a Spanish lady Countess del Cinchon. In 1820, two French chemists Pierre Joseph Pelletier and Joseph Bienaime Conventou succeeded in extracting the alkaloid of quinine from cinchona bark, and commercial production of quinine began in 1827. Until the 1850s all the world's cinchona bark came from the forests of Peru, Bolivia, Ecuador, and Colombia, where the trees grew wild. The British and the Dutch interests then decided to grow the trees in Asia. In 1858-60, Clements Robert Markham (1830-1916) assistant secretary at the India Office aided by a gardner at the Royal Botanic Gardens at Kew secretly travelled to Bolivia and Peru and brought back seeds of the Cinchona calisaya tree; while English botanist Richard Spruce brought seeds and young plants of C. Succirubra from Ecuador. Intense experimentation at the Indian botanical gardens made India self-sufficient in quinine. Almora-born British physician Ronald Ross (1857-1932) discovered in 1897 that the germ of malaria is carried by Anopheles mosquito, and received the 1911 Nobel prize. Not unexpectedly, he could carry out his research only intermittently 'during his spare time when he was not on duty as regimental doctor' and entirely at his own expense. Later, in 1904 Ross served as a consultant at Panama where the long-needed canal could finally be built only when malaria was eradicated.

Botanical survey of India: The botanical gardens carried out systematic, geographical and economic studies' of Indian flora, and finally in 1891 Botanical Survey of India was constituted. The Company did not mind enrichment of science as long as it took place in the normal course of its own activities. But the moment it was asked to extend patronage to science for the sake of science, it baulked. In 1851, notwithstanding a memorandum from the British Association, the Company refused to promote a project on Flora Indica by Dr. Joseph Dalton Hooker of Kew and his collaborator Dr Thomas Thomson (1817-78), later the superintendent of Calcutta Garden 1854-61. Hooker's monumental seven-volume Flora of British India (1875-97) had to wait for orders from the Secretary of State.

The British desire for exploration and increased revenue led to the epoch- making discovery of fossil fauna in the Shivalik hills. The story deserves to be told in some detail, because it brightens a particularly dark period at Delhi. As early as AD 1357, Ferozeshah Tughlaq cut through a hill with the help of 50,000 men to dig a west Yamuna canal. East Yamuna, or doab canal, was dug up later, during the Mughal period. Both these canals had ceased to flow by the middle of the eighteenth century. The British government took up the question of restoring these two old canals. After preliminary survey in 1810-11, work on the Ferozeshah canal was begun in 1817, and on the doab canal in 1822. The head of the two canals, Saharanpur, was also the seat of a public garden that was established in 1779 by the Rohilla Fauzdar, Zabita Khan, who appropriated the revenue of seven villages for its maintenance. His son Ghulam Qadir, who pitilessly blinded the hapless Mughal emperor Shah Alam in 1788, continued the arrangement, and so did the Mahrattas after him. In 1823 Marquis of Hastings converted it into a 400-acre botanical garden, to which was later added a nursery of trees for canal banks. Dr Hugh Falconer (1808-65) of the Bengal Medical Service, who in 1832 became the director of the Saharanpur garden, was aware of a report by Ferozeshah's historian Farishta where he described unearthing of three yard long bones of giants while digging the east canal. In 1831, Falconer along with Sir Proby Thomas Cautley (1802-71), in charge of the doab canal, discovered fossil bones. On 16 November 1834 Lt (later Sir) William Erskine Baker (1808-81) superintending engineer, received a present of a fossil of an elephant's tooth from the Raja of Nahan. He sent a sketch to the secretary of the Asiatic Society Calcutta. On hearing this Dr. Falconer made enquiries, and had a fragment of a similar tooth presented to him also.

These discoveries proved that in the remote past a sea occupied the valleys of the Indus and Ganga. The well-known pattern of the Company's attitude towards science is repeated here. Dr Falconer wanted to devote his full time to his great work Fauna Antiqua Sevalesis, but as a 1878 Memoir puts it he 'was not spared to complete it. This work was edited and published after his death. Steam navigation, telegraph, and railways helped tighten British grip over India. The practice of government sponsored. science to serve the practical need of the administration continued throughout the British rule. Thus there came about India Meteorological Department (1875); Imperial Bacteorological Laboratory (1890) at Poona, later shifted to Mukteswar; Imperial Agricultural Research Institute (1903) at Pusa in Bihar, later shifted to Delhi; and Zoological Survey of India (1916).

The last scientific act of the British Indian government was dictated by the second world war which in turn brought about its exit from India. In 1942 Council for Scientific and Industrial Research was set up for providing scientific support for the war effect. Note that the actual number of scientific officers was very small. In 1920 the biggest of the scientific services, Survey of India, had a total of 46 imperial grade officers, while the Botanical Survey had only two.

We have seen that the British rulers were. Not interested in science as such,but in using science to further their interests. Whenever their practical needs pointed a finger towards a particular branch of science, attention was paid to that science. Harnessing science enriches it also. Thus in the process of empire building, India was added as a laboratory to the edifice of modern science. Introduction of Indians to science came about when they were assigned the role of laboratory assistants. They soon graduated to respond to science on their own initiative.

3.1.4. Natural History in India during 18th-19th centuries

European access to India was a multi-dimensional phenomenon. The merchant-rulers were keen to identify commodities that could be profitably exported to Europe, cultivate commercial plants in India that grew outside their possessions, and find substitutes for drugs and simples that were obtained from the Americas. The ever increasing scientific community in Europe was excited about the opportunities that the vast landmass of India offered in natural history studies. On their part, the Christianity enthusiasts in Europe viewed European rule in India as a godsend for propagating the Gospel in the east. These seemingly diverse interests converged at various levels. Christian missionaries as a body were the first educated Europeans in India. Like in philology, they were pioneers in natural history also. They constituted a valuable resource for naturalists in Europe. European interest in their field work brought them scientific recognition as well as the much needed cash. More significantly, they introduced the colonial administrators, especially the medical men, to systematic botany.

Europe was introduced to western Indian drugs and simples by the 1563 work of the Goa-based Portuguese physician Garcia d'Orta (1501-1568). A century later, during 1678-1693, the Dutch administrator Hendrik Adriaan (1636-1691) furnished Europe with information from south India. In both cases, the initiative originated in the colonies itself. Things changed in the second half of the 18th century. Now, individual European naturalists and institutions wanted not only specimens from India but also bits of tacit knowledge resident in local population. The European India was ready and willing to oblige, but as a collaborator rather than a courier. We shall focus on India-based Europeans who built a scientific reputation for themselves; there were of course others who merely served as suppliers.

3.1.4.1. Advance of Natural Sciences in India

As in geography, the earliest centre for botanical and zoological research was south India. Europe dictated scientific botany was begun in India by a direct pupil of Linnaeus not in the British possessions but in the tiny Danish enclave of Tranquebar which though of little significance as far as commerce or geo-politics was concerned came to play an extraordinary role in the cultural and scientific history of India.

Using Tranquebar as their (initial) base, the missionaries carried out field work in the whole of peninsula as well as Ceylon. They made their own investigations, supplemented them with traditional knowledge obtained from local people, and passed on the package to Europe where it was handsomely acknowledged and incorporated into the mainstream. These activities produced profound impact on British India as well. Its introduction to scientific biology came from interaction with missionaries-cum-naturalists and led to its institutionalization. Tranquebar even served as a waiting room for entry into British India. Capable persons from Europe came to the Danish enclave confident that sooner than later British India would absorb them.

Tranquebar is well known for the Royal Danish Mission established in 1706. While the India-bound Lutherans were taught theology in Halle, those who additionally wanted education in science subjects were sent to Copenhagen. It was however not this mission but the Moravian Mission which took the lead in the 'systematic investigation of Indian vegetation'. The latter was established in 1760 on the outskirts of Tranquebar with the permission of the Danish King. It was meant to serve as a base for religious activity in Nicobar. It failed in its religious mission and was closed in 1803, but it did leave behind its scientific impact. The first modern botanist in India was Dr Johann Gerhard Koenig (1728-1785) who arrived in 1768 and remained in India till the end, though not with the Mission. Koenig was born in the duchy of Courland, now in Latvia, and was originally trained as a pharmacist in Riga. In 1748 he took appointment in Denmark. During 1757-1758 he studied natural history in Uppsala as a student of Linnaeus with whom he maintained correspondence. In 1759 Koenig was appointed to the Royal Frederick's Hospital in Copenhagen as a surgeon and pharmacist, being by special permission allowed to study medicine at the University. In 1764 he became amanuensis to Georg Christian Oeder, curator of the newly launched Flora Danica project. It would seem that Koenig's proximity to Linnaeus did not go well with Oeder, and Koenig was left with no alternative but to move out. He came to India to pursue his vocation as a naturalist. His dissertation, dated 1773, was submitted in absentia under Professor Friis Rottboel. Koenig then may well be the first person in India with a scientific doctorate from a European university.

Koenig was unable to fund field trips from his meagre Mission income. In 1774, he accepted the post of naturalist to the Nawab of Arcot. The appointment allowed Koenig frequent excursions to the hills and even a voyage to Ceylon. Payments to Koenig however were irregular and in 1778 Koenig successfully applied to the Madras Government for appointment as the Company's first-ever natural historian. In 1778-1780 he was sent to Thailand and the Straits of Malacca to bring economic plants such as cardamom and gamboges for cultivation in India. He also brought information on tin ore and minerals. For himself, he collected huge information on Thai orchids.

Indian botany was greatly supported by Sir Joseph Banks (1743-1820), well known botanist, influential scientist, and a friend of King George III. He was appointed the director of Royal Botanic Gardens at Kew in 1773 and president of the Royal Society in 1778, both of which positions he held till his death. Luckily, Bank's secretary Daniel Carl Solander (1736-1782) who had also studied in Uppsala was Koenig's 'learned Friend and Fellow disciple'. Banks declared that Koenig had repaid the Company 'a thousand-fold over in matters of investment, by the discovery of drugs and dying materials fit for the European market'. Koenig bequeathed his manuscripts and herbarium to Banks. Koenig dutifully sent his results to his friends in Europe and to Banks. There are three shells in the Linnaeus collection marked Tranquebar. The name of the sender however is not mentioned. On 20 December 1771, Linnaeus wrote to a friend, John Ellis, that 'Koenig had found a lot of new things in Tranquebar'.

Koenig's earliest pupils and collaborators were the two missionaries from the Danish-Halle Mission: Christoph Samuel John (1746-1813) who arrived in 1771 and Johan Peter Rottler (1749-1836) who came in 1776. Both remained here for the rest of their life. From among others, the most famous is Dr William Roxburgh (1751-1815) who was hailed by his contemporaries as father of modern Indian botany. Much later, after Koenig's death, two other names became well known: Johann Gottfried Klein (1766-1821) and Dr Benjamin Heyne (1770-1819). Johann Klein was a local boy. He is the first India-born modern botanist. His father Jakob Klein (1721-1790) was a Lutheran missionary who came to the Danish Mission in 1746 and remained here till end. Junior Klein was born in Tranquebar, went to Copenhagen to study medicine and returned in 1791 as the mission doctor. His 30-page dissertation dealing with the treatment of venereal disease in India was submitted to the University of Copenhagen and published in 1795.

'Nomenclature has always been regarded by systematic botanists as practically the most important department of their science, of which classification is the framework, and in no other department of knowledge so much careful attention been paid to it'. The specimens were transmitted to Europe, many of which were published in different works, sometimes under the names given by the donor, sometimes under a new name. The fact that India-based European naturalists decided to give names themselves shows their level of confidence and knowledge. What the India-based European botanists lacked by way of access to current scholarship and publications was more than made up by the novelty of the material in their hands.

In 1792, Johann Reinhold Forster (1729-1798) wrote to the missionaries in south India asking for information on poisonous snakes and traditional antidotes. John collected the information and sent it to Forster. Similarly, John was of great assistance to Berlin-based Marcus Elieser Bloch (1723-1799) who emerged as the pioneering authority on fishes with his well-illustrated 12-volume Natural History of Fishes published during 1785-1799. It is interesting to see Indian fishermen's common knowledge emerging as a European research finding. Bloch named three fishes in John's honour. He similarly honoured Rottler and Klein. In 1795, John received a doctorate from Erlangen University.

Rottler remained with the Tranquebar Mission only for eight years, that is till 1804 when he transferred to the Company's service in Madras. At the close of 1795, Sir Hugh Cleghorn (1752-1837), the first colonial secretary to Ceylon, was deputed by the government to make a general tour of the island. He engaged Rottler 'at a very moderate expense' to accompany him as a Tamil-English interpreter and naturalist. Rottler stayed back for some time to 'render his assortment more complete'. Rottler's Ceylonese collection was subsequently incorporated into the general herbarium at King's College London. Indian flora reached Canada also. Sir Thomas Andrew Lumisden Strange (1756-1841) the chief justice of Nova Scotia during 1789-1797 served as the first chief justice of Madras Supreme Court 1801-1817. In 1802, Rottler and Klein presented a collection of 168 plant specimens to Strange which he in turn passed on to King's College, Windsor.

Rottler was in contact with various professors in Europe: Johann Christian Daniel von Schreber (1739-1810) in Erlangen, Carl Ludwig Willednow (1765-1812) in Berlin, and Martin Hendriksen Vahl (1749-1805) in Copenhagen. In 1795 Schreber was instrumental in getting both Rottler and John the degree of doctor of philosophy. The same year Rottler also received the honorary degree of doctor of physical sciences from the Imperial Academy of Vienna. Rottler is the first India-based botanist to publish in European journals. In 1830 as part of his missionary duties Rottler began work on his Tamil-English dictionary which was partly published in his own lifetime in 1834. An interesting feature of the dictionary is that it 'contains a very extensive list of the vernacular names of South Indian Plants, with the technical names by which they were known attached, not a few of them were of his own choosing; and this list will be found to be of very considerable help to Botanists in identifying the plants prescribed in the earlier letters on Indian Botany'.

The early botanical studies were merely a recreation for the missionaries turned botanists; their more important duties were 'instructing the natives of India in the wisdom of the west, and of thus fitting them to become partakers of the promise of the Gospel. In fact botany became a compensation for the missionaries for their failure on the evangelical front.

In 1785 Koenig was succeeded by Dr Patrick Russell (1726-1805) who was already in India on his own. Russell came to Vizagapatam in 1782. One of Patrick's very first tasks after arrival was calling on Koenig in Tranquebar. In Vizagapatam Russell did not confine his attention to the vegetable kingdom alone but eagerly collected, figured, and described the fishes and the serpents in the Carnatic plain which stretches along the coast of Coromandel. On appointment Russell was asked to catalogue the economically useful plants of Madras and publish Koenig's scientific notes. It was however not sufficient that the Company naturalists worked for the government. They must be of help to the scientists back home also. Far-sightedly, he suggested to the Madras Governor that information on all economically useful Indian plants be collected. 'He proposed that letters should issue from the highest authority, inviting the gentlemen, particularly of the medical department, resident at the different stations, to transmit every information in their power concerning such useful plants, accompanied with specimens of each plant, including the leaf, flower, and fruit, with a view to publication.' Russell's plan, with a list of the plants he had selected to begin with, was approved by the Court of Directors which requested Banks to oversee the project. Russell left in 1789, but the project continued.

Russell's greatest contribution was his initiation of a study of snakes. This was a subject of great importance because visit to tropical lands also meant encounter with snakes. He wished to educate the people on the distinction between poisonous and non-poisonous snakes so that a snake bite did not always cause fear and anxiety, and harmless snakes were not killed out of ignorance. Harmless snakes have teeth in both upper and lower jaw while the poisonous snakes do not possess upper teeth. It may not be prudent to check the teeth while the snake is still alive. Keeping this in mind, he prepared detailed description of various snakes, towards the end of 1787. His write-up and figures were published by the government and widely distributed. His major publications came out after his return to Britain. Some of the snakes of Indian landmass were named after this great natural historian.

After Russell, there came a man of outstanding merit and long service. Edinburgh-educated Roxburgh who probably an illegitimate son of an influential family in Scotland was able to overcome the disadvantage of birth, thanks to the social patronage received from the Boswells of Auchinleck and the professional patronage from Professor John Hope and Sir John Pringle, President of Royal Society during 1772-1780. He began his career as a surgeon's mate on Company ships and joined Madras medical service as an assistant surgeon in 1776. In 1781, he was appointed surgeon to the garrison at Samulcotta in what was known as Northern Sircars. Located at the edge of a hilly region, 27 miles from one of the mouths of Godavari river, Samulcotta is endowed with 'a very interesting Flora', and was the site of an old Mughal garden. Now, Roxburgh established a Company garden and began to develop a collection of living plants which he studied for their economic value. In the task of collecting, sorting and naming his material, Roxburgh received direct help from Koenig. In 1786, he reported the significant discovery that 'the Pepper Plant was a native of the Hills in the Rajamundry Circar'. During 1787, Roxburgh procured 400 slips of the pepper vine from the Rampa hills, and within 12 months raised upwards of 40,000 plants. He cultivated coffee, and worked on a number of topics including various dyes including lac and caducay gall; culture and manufacture of silk; and various grasses. He spent considerable time and energy on the study of Swietenia febrifuga as possible substitute for cinchona.

Within the overall ruthlessness of the Company, there was individual thoughtfulness which was listened to. Although Roxburgh could not have pointed to the Company how its policies caused famines in India, he suggested that cocoanut trees be planted on canal banks and street side. He also advocated the cultivation of the sago, date, palmyra, plantain, jack, bread-fruit and opuntia, all of which possess food value. He also experimented with teak, which would become a priority in the Calcutta garden. In addition to the Company garden which he supervised Roxburgh set up a private garden of his own.

On the basis of the botanical work he carried out at Samulcotta and Patrick Russell's recommendation, Roxburgh was appointed Russell's successor as the Madras naturalist. We have already noted Russell's proposal for a systematic publication of Indian flora. Roxburgh immediately began work on the project.

In 1793, Roxburgh left Madras to take over as the first full-time salaried superintendent of the Calcutta Botanic Garden, and the project went with him.

Calcutta: (1787-1846) Initiative for Calcutta Botanic Garden came from Lieutenant Colonel Robert Kyd (1746-1793), secretary to the military department in Calcutta, and a horticulture enthusiast who cultivated a private garden of his own. On 15 April 1786 Kyd suggested to the government that plants of the Sago tree growing in the Malay peninsula be brought and grown all over British possessions. He followed this up with a broader proposal, couching it in a mercantile idiom he knew the Company would understand. The letter was accompanied by a long list of plants he wanted for the garden including Dacca cotton, indigo, teak wood, pepper, cardamom, gum copal, nutmeg, clove, tea green, China laquer, and papia. The Court of Directors consulted Banks who supported the proposal and emphasized the need for reciprocal exchange of plants and seeds between Calcutta and West Indies. The Company accepted Kyd's proposal on July 1787, seeing 'a great source of wealth' for itself in the cultivation of cinnamon, which would break the Dutch world monopoly.

Accordingly, a botanic garden was established in 300 acres in Sibpur on the banks of Hooghly, with Kyd as its honorary superintendent, and with his private garden merged into it. For Roxburgh there was continuity between Samulcotta and Calcutta. Between 1790 and 1795 he transmitted about 500 specimens with drawings and descriptions to England. The final product of the monumental effort was the Plants of the Coast of Coromandel, with a preface by Russell. The first volume was published in 1795, the second in 1798, and the third as late as in 1819. In 1805 when it seemed that Roxburgh's illness would render his post vacant, Banks reminded the Company that the superintendent of the garden should be 'capable of communicating advantageously to the learned world such discoveries in the animal, the vegetable and the mineral kingdoms as are made from time to time in the extensive regions of the east to the intimate advancement of natural knowledge'.

This was a significant observation which the Company accepted. By this time, the British government had a say in the Company affairs and scientists in the British government. Calcutta Botanic Garden was no longer a mere Company depot, but an international research centre. After Roxburgh's departure in 1813 the Garden remained leaderless for four years. Roxburgh handed over charge to William Carey who held it till April 1814. In 1814 itself Carey published from his Serampore mission press a catalogue of the plants growing in the garden, under the title Hortus Bengalensis, with financial support from the government. This was an important development, because Europe at large learnt about the garden from it. Carey's own 12-page introduction sums up the progress of the Garden up to that time. At the beginning of Roxburgh's term the Garden had about 300 plants. By the time he left in 1813, the Garden had an inventory of about 3500 plants.

Francis Buchanan was appointed the superintendent in 1814 but he left in 1815. It would be another two years till the Garden got a permanent director. Nathaniel Wallich's (1786-1854) association with the Garden began under the shadow of war. Wallich was educated at Copenhagen under Professor Martin Vahl (1749-1804). But since he was a Jew (his original name was Nathan Wolff), he could not have been employed in Denmark itself. Wallich arrived in the Danish enclave of Serampore as a surgeon in November 1807. When in 1808 the British annexed Danish territories in India in continuation of developments in Europe, he was among the prisoners of war taken. He was released, on 1 January 1809, on Roxburgh's intervention, to be employed at the Garden. Wallich was absorbed in the medical service in 1814. The same year he proposed to the Asiatick Society the establishment of a museum which blossomed into Indian Museum.

He held temporary charge of the Calcutta Garden from 24 February 1815 till 20 April 1816. Eventually Wallich was given the regular appointment from 1 August 1817 which he retained for thirty long fruitful years, till his retirement in 1846. It may be noted in passing that Sanskrit studies in continental Europe were similarly initiated by a prisoner of war, in 1803. The prisoner was a British Alexander Hamilton and the venue Paris. There was thus a certain collectivity in European intellectual pursuits. Wallich's tenure 'constitutes the most prominent era in the botany of India'. At his suggestion, the government allotted an area, five miles in circumference, for the Garden, and employed upwards of 300 gardeners and labourers. Subordinate gardens were formed in remote parts of the Indian possessions; collectors were sent out to discover new, and especially useful, plants; and the British residents were invited to send the vegetable productions of their respective districts to Calcutta, both in a living and dried state.

Four years later, in 1820, Wallich came over and spent more than a year assiduously collecting specimens for more than a year in the vicinity of the capital. Since the interior was closed to the Europeans, he arranged for local collectors. He was thus able to add a fair knowledge of the alpine flora to the abundant information on the temperate and tropical regions that he obtained by his personal exertions. Before returning, he trained a number of collectors, who continued, during a long series of years, to transmit dried specimens from Nepal.

One Mr Blinkworth, an active collector, at the same time, explored Kumaon, and Mr. Gomez contributed extensive collections from the rich province of Sylhet, and from the neighbouring Khasia hills, while Wallich himself visited Penang and Singapore, thus adding a knowledge of the Malayan flora to that of the rest of India. In 1825, he examined and collected the plants of the kingdom of Oude and the province of Rohailkhand, the valley of Dehra, etc. His last mission was to Ava.

Saharanpur Garden: Next in importance to Calcutta there stood the Saharanpur Garden which was a revival rather than a creation. A 40-acre public garden aptly called Farhat Baksh was established at Saharanpur in 1779 by the Rohilla Fauzdar Zabita Khan who appropriated the revenue of seven villages for its maintenance. Saharanpur passed into British hands in 1803. In 1816 George Govan (1787-1865) who had joined as civil surgeon at Saharanpur the previous year wrote a letter to the Governor General strongly arguing for the revival of the old, now dilapidated, garden. In particular he advocated the cultivation of chocolate, guaiacum, cassia, liquorice, vanilla, and 'various species of cinchona furnishing the Peruvian bark'. His advocacy of tea cultivation anticipated later developments.

He very sensibly pointed out that tea could not be unique to China and should grow in conditions similar to those in tea growing parts of China. The Governor General agreed that 'considerable advantages would result not only to Science but to the interests of the Honourable Company from the proper management of the Botanic Garden at Saharanpur'. Govan's appointment as Superintendent was sanctioned on 13 June 1817. Govan's tenure however was short. In 1821, he left India on sick leave and Saharanpur for good. When he resumed duty, it was as a geologist. Like in Europe, natural history served to decrease the distance between the aristocrat and the commoner. In 1827 at the newly founded hill station of Simla, Lady Amherst and the Governor General Lord Amherst liked to go out every morning after breakfast with Dr Govan 'walking or rather scrambling up the mountains in search of plants'.

In Govan's time the Saharanpur Garden was an independent entity, but after him it was placed under the control of the Calcutta Garden. Many Saharanpur superintendents in fact rose to head the latter. In 1823, the Saharanpur charge was handed over to the civil surgeon John Forbes Royle (1798-1858). Kanpur-born Royle was educated at Edinburgh and Addiscombe with a view to a career in army like his father, but thanks to his pupilage of Anthony Todd Thomson (1778-1849), he became interested in botany, obtained his diploma and came to Bengal in 1819 as an assistant surgeon. In 1823, he was appointed the superintendent of the now 400-acre Saharanpur gardens which position he held till 1831. Scientifically the Calcutta and Saharanpur gardens were complementary; commercial plants which would not grow in the former had a chance in the latter. Royle returned to England in 1831 bringing duplicates of all his collections with him. After a long spell of leave, he retired in England in 1837. The same year he took the M.D. degree from Munich.

In 1833, he published the first part of his Illustrations of the Botany and Other Branches of the Natural History of the Himalayan Mountains, and of the Flora of Cashmere. The second part, containing the plates, came out in 1839. On the opening of King's College London in 1836, Royle was appointed lecturer on materia medica which post he filled till 1856. On the basis of his course material he published in 1837 An Essay on the Antiquity of Hindoo Medicine. From 1847 to 1857 he was reporter on economic products to the East India Company. In a lecture delivered at the Society of Arts in 1854 during the war with Russia Royle drew attention to India as a source of various fibrous materials used in the manufacture of cardage, clothing, etc. The lecture was expanded into a valuable book *On the Fibrous Plants of India*, published the next year. He took an active interest in cultivation of tea in the East Indies. Royle's life sums up a capable European botanist's professional career driven by India : collection of live plants and specimens in India; enrichment of herbariums in Britain; and advancement of Company's commercial interests.

Royle was succeeded by Hugh Falconer (1808-1865) who made a name for himself by the discovery of the Shivalik zoological fossils. Falconer first studied at the University of Aberdeen, 'aided by the resources' of an elder brother who was a merchant in Bengal. In 1830, he obtained his M.D. from Edinburgh and was almost immediately appointed assistant surgeon in Bengal. Since he had not yet reached the required age of 22, he came to London to assist Wallich in the distribution of the herbarium. At the same time, he studied the collection of fossil mammalia from the banks of Iravati River which had been brought by John Crawfurd during his mission to Ava and which was now housed in the museum of Geological Society of London.

Falconer joined Bengal Medical Service in September 1830 and met Royle in April 1831 in Saharanpur when his official duties brought him there. On Royle's recommendation, Falconer was speedily appointed to officiate for him during his leave of absence. When Royle left for England in 1832, Falconer succeeded him. 'Thus, at an early age of twenty-three, did he find himself advanced to a responsible and independent public post, offering to a naturalist the most enviable opportunities for research; so fertile was the Indian service then in chance to rise for any young officer who chose to make the exertion'.

Fossil fauna: In 1847 Falconer became the superintendent of the Calcutta Garden as also professor of botany in the Medical College there. The British desire for exploration and increased revenue indirectly led to the epoch making discovery of fossil fauna in the Shivalik hills. The British Indian government took up the task of restoring the old west and East Yamuna canal dug during the sultanate and Mughal era. After preliminary survey in 1810-11, work on the Ferozeshah canal was begun in 1817, and on the doab canal in 1822, Saharanpur being the head of both. Sir Proby Thomas Cautley (1802-1871), in charge of the doab canal, had already discovered fossil bones, but their real nature had been overlooked. Falconer was aware of a report by Ferozeshah's historian Farishta where he described unearthing of three yard long bones of giants while digging the east canal. Towards the end of 1831, Falconer and Cautley discovered bones of crocodiles, tortoises, and other fossil remains in the tertiary strata of the Shivalik hills. Cautley was able to follow the lead by discovering more fossils through blasting the hills. On 16 November 1834, the superintending engineer Lieutenant (later Sir) William Erskine Baker (1808-81) received a present of a fossil of an elephant's tooth from the Raja of Nahan. Promptly, he sent a sketch to the secretary of the Asiatick Society Calcutta. On hearing this, Dr Falconer made enquiries and had a fragment of a similar tooth presented to him also. These discoveries proved that in the remote past a sea occupied the valleys of the Indus and Ganga. Incidentally, in 1835, Falconer and Cautley discovered the remains of the giant Miocene fossil tortoise.

It would be instructive to see how the colonial researchers 'far distant from any living authorities or books on Comparative Anatomy to which they could refer' carried out their work. In the surrounding plains, hills and jungles, 'they slew the wild tigers, buffaloes, antelopes, and other Indian quadrupeds', and preserved their skeletons. 'They also obtained specimens of all the reptiles which inhabited that region'.

Falconer's 1868 biographer smugly noted that 'the white man had to draw on local means in all emergencies'; 'but the intelligence, docility, and exquisite manual dexterity of the natives, backed by their faith in the guiding head of the European, furnished an inexhaustible fund of resource'. To construct a barometer for mountain exploration, broken tumblers were melted and blown into a tube; mercury was distilled from cinnabar purchased in the bazaar; and 'a brass scale was cast, shaped, and even graduated, by a native blacksmith, under the superintending eye of the European amateur'. In 1837, both Falconer and Cautley were jointed awarded the prestigious Wollaston Medal of the Geological Society of London. It has been suggested that the award 'had great symbolic value, not just for the recipients but for all geologists working in India'. It 'was taken as evidence that the geology of India, and those labouring in its elucidation, were considered important by metropolitan savants'

Discovery of Shivalik fossils was an extraordinary find. It emerged as a corollary of giant government undertaking, namely digging of canals, and burst on the scientific scene. There can however be no doubt that no matter what the driving force for field studies in India, recognition by the British scientific power centres was coveted and solicited.

In 1842 Falconer left for Europe on sick leave and remained there till 1847. He brought with him his natural history collections amassed during ten years of exploration. These included 70 large chests of dried plants from Kashmir, Afghanistan, Tibet, Punjab, Himalaya, plains of what is now western Uttar Pradesh, and from the neighbourhood of Darjeeling, Assam and Sylhet. His collections from Kashmir and Little Tibet were particularly valued, he being one of the first botanists to visit these areas. His collection also included 48 cases containing five tons of fossil bones, together with geological specimens, illustrative of the Himalayan formations from the Indus to the Gogra, and from the plains of the Punjab across the mountains north to the Mooztagh range.

Cautley had already (1840) deposited his collection with the British Museum, the transportation costs from India being paid by the Indian government. Falconer's collections were divided between East India House and the British Museum. There were other fossil collections in the university museums in Oxford and Edinburgh. In July 1844, the presidents of various learned societies sent a memorial to the Court of Directors pointing out the desirability of having the specimens in the various collections prepared, arranged and displayed and also of publishing an illustrated work to convey to the men of science a 'knowledge of the content of Sewalik Hills'. They further suggested Falconer's name for carrying out this work. Since the Company does not seem to have been too enthused with the idea, the President of British Association for the Advancement of Science along with the presidents of other societies asked Her Majesty's government for support. The government responded promptly by making a grant of 1000 pound sterling to prepare the materials in the British Museum in a paleontological gallery. In December 1844, Falconer was entrusted with the work. The Company now fell in line, treating Falconer on duty.

Both the Company and the British government agreed to buy 40 copies Nine of the envisaged 12 parts of the illustrated work titled Fauna Antiqua Sivalensis were published within three years. In June 1847, on Wallich's retirement, Falconer was appointed superintendent of Calcutta Botanic Garden and professor of Botany at Medical College. He would have liked to work on his on the Shivalik fauna in London on his Indian salary. But the Company refused to extend Falconer's stay in London, compelling him in December 1847, under threat of loss of pension, to return to his duties in India. Falconer tried to resume the work in 1856, on his return to England after retirement, but eventually the work was completed in 1868 after his death.

Discovery of Coal: From coal to continental drift Early British India did require some coal for use by its arsenal for casting ordnance. This coal was imported from England. As early as 1774, attempts were made to replace sea-coal with Indian coal but the experiment was not a success. The initiative came from a Bengal civil servant, Suetonius Grant Heatly (1741-1793 at the time the commissioner of Chhota Nagpur and Purnea. The area included the hilly Ramgarh country where Subarnrekha river runs for some miles through a coal mine. Heatly in collaboration with some other civil servants obtained the lease for working six mines in

Pachete and Beerbhoom. The enterprise however failed because, the entrepreneurs felt, the Government refused to buy coal 'owing to the strong interest made by the coal contractors at home'. As England industrialized, it needed the coal for itself. At the same time demand in India also increased with the result that England could not supply it to India in sufficient quantities year after year. In September 1808, the Governor General, Earl of Minto, asked the Military Board to examine 'the practicability of substituting Bheerbhoom coal for sea-coal'. It was however only in 1814 that the government decided to sponsor quest for better quality coal. One William Jones (d. 1821), was hired for coal exploration. The result of his mission was that he re-discovered some of Heatly's old workings and more importantly 'discovered' the Raniganj seam. Jones was the first person to bring Indian coal to the general market. This historical distinction notwithstanding, he could not make a commercial success of his enterprise. In 1836, the mine passed on to a firm owned by Dwarkanath Tagore, giving him virtual control over the fuel supply in the Bengal presidency, with the government as the biggest buyer.

While the British Indian government was interested in coal for local use, the Court of Directors eyed the Himalayan region's legendary mineral wealth for its own profit. The first geological appointment in British India was an imposition from the very top, with disastrous results. A more systematic approach was initiated at the time of reorganization of the Great Trigonometrical Survey of India (GTS) in 1818, when it was decided to appoint a surgeon and geologist to the survey. University trained surgeon turned naturalist, Henry Wesley Voysey (1791-1824), who joined towards the end of 1818, was the first effective geologist in India. He wrote a report on the stone used in the construction of Taj Mahal which he visited in 1822. While influential geologists in Britain were keen to expand their zone of influence, 'much of the impetus to increased geological activity originated within India rather than from Britain'. Introduction of steam machinery in manufacture and in river and ocean navigation brought home the realization that local coal was more important than local diamonds. A six-member committee was set up in 1835 for investigating the coal and mineral resources of India with Dr John McClelland (1805-1875) of the Bengal medical service as its secretary. Its report submitted in 1838 largely dealt with coal. The work done so far had been sporadic and isolated. Time had now come for a systematic survey. England had already done so. England instituted Ordnance Geological Survey in 1835 with Sir Henry Thomas De la Beche (1796-1855) as its director. The same year, a Museum of Economic Geology was established, also under Beche. In February 1846 David Hiram Williams (c. 1812-1848), who had earlier assisted Beche in the survey of coal field of South Wales, took up appointment as the Geological Surveyor in the Service of the East India Company. His reasons for accepting the assignment were primarily financial.

The Company's directions to William were explicit: 'you will direct your principal attention to those localities which promise to afford supplies of coal, and which are so situated with respect to water carriage, as to give a real commercial value to the coal which they may produce'. The geologists travelled on elephants who were trained to pick up fossils.. During one of his field explorations, Williams fell off from an elephant, and again from a precipice; and caught jungle fever from which he never recovered.

Like many other impoverished young professionals in Britain and Ireland, European professionals in India believed that their financial interests, the Company's commercial interests and Europe's scientific interests would all converge. William hoped that the survey of Indian coalfields 'will eventually turn out both in an economic point of view and a branch of the Geological Survey of Great Britain. Like many other Europeans in India, Williams also complained that the establishment back home was not very responsive to his work. He sent fossil plants from Indian coal-beds to the British Geological Survey in 1847. Hooker later recorded that Williams 'complained that of all the letters he had written to the Survey but one was answered & the magnificent series of coal fossils not even acknowledged'. In general, European scientists based in India were able to make an impact back home only if they were suitably networked.

Hiram Williams was succeeded by Thomas Oldham (1816-1878) who was at the time professor of geology at Trinity College Dublin as well as the local director of geological survey. He joined his post in India on 5 March 1851 and held it till 1876. In 1856, the survey was constituted as a government department under the name Geological Survey. Under the Survey, geological explorations would continue uninterruptedly and move from merely the economic to the manifestly scientific. In 1863, Blanford noted that though the coal in the Ramghur and Bokaroh coal fields was of poor quality, they offer ' many points of very high interest to the geologist'.

A high point of Indian geology was Indian coal was 'not of the best quality', but it 'offers many points of very high interest to the geologist'. What began as simple quest for coal ended in providing the evidence for the continental drift hypothesis. The Trinity College Dublin-educated Henry Benedict Medlicott (1829-1905) left the British Geological Survey to take up an appointment in the Geological Survey of India in 1854. From 1855 then till 1862, he taught geology at Roorkee Engineering College but remained available for survey work. Finally, in 1862 he returned to the Geological Survey. He succeeded Oldham as superintendent in 1876, designated director in 1885, and retired in 1887. In 1872 in an administrative report he used the term Gondwana system for coal-bearing formations. The term is now used in preference to the tautological Gondwanaland for a hypothesized supercontinent in the southern hemisphere.

We have seen above that Williams took charge as Geological surveyor in 1846, and Oldham was appointed as his successor in 1851. When his contract was renewed six years later, the same designation was used. The term geological survey of India was employed in a descriptive sense till in 1856 it was given a specific meaning as a government department. It is relevant to note that the Survey of India takes its roots back to the 1767 appointment of Rennell as Surveyor General of Bengal. In any case, Survey of India , Geological Survey and the Medical Service were the only three science services in the British India under the Company rule.

Madras (1793- 1853): On the transfer of Roxburgh to Calcutta in 1793, Benjamin Heyne, who had been strongly recommended to Roxburgh by Rev. C. S. John, was appointed superintendent of the Madras Presidency's pepper and cinnamon plantations. His own major interest however lay in geology. He wrote on diamond and copper mines and on garnets as also on iron smelting industry. In 1795 he submitted voluminous reports on diamond mines in Malavelly and iron smelting industry in Ramanaikpetta near Ellore. The next year he wrote on copper mines at 'Agrcondula in the District of Innacondah', which had been neglected or abandoned for two centuries. He also wrote on garnets, and the geology of the 'Boggleconda Hill' near Innaconda.

The 1799 defeat of Tipu of Mysore was an event of great administrative and scientific significance. So far the Company had been confined in the peripheral areas in South India, but now it became successor to a well-run state. Its territories now extended from the east coast to the west. From a scientific point of view this was an exciting development because the new lands presented different flora and geology. Post-Tipu, the first task for the Company was the compilation of maps from whatever 'meagre and unsatisfactory material' was already extant. Next, the Governor General ordered a thorough and systematic Mysore survey It was to comprise two components. The mathematical survey would fix the external boundaries and also lay down the 'Country in detail' through primary triangulation. The physical survey would deal with botany, mineralogy, medicine; diseases, weather, rains, soil, agricultural produce, animals, revenue, population, etc. The survey was placed under the overall charge of Colin Mackenzie, while Francis Buchanan was appointed to investigate 'the state of agriculture, arts, and commerce, in the dominions lately acquired from Tippoo Sultan'. The departments of botany, mineralogy and natural history were entrusted to Benjamin Heyne For his Mysore survey establishment, Heyne drew on Samulcotta. It included a European painter; two local painters; two plant collectors who were 'natives accustomed to this service'; and three peons and harkaras for preserving and carrying minerals, plants, and other objects of natural history. Bangalore already had a beautiful garden, known as Lal Bagh. It was placed under Heyne's charge, to be appropriated as a botanical garden.

In 1802, he was made independent of Mackenzie's survey and given the appointment of Madras naturalist. For about two years 1812-1814, he was in Europe on furlough. In 1813, he passed on a considerable number of plant specimens to the German botanist Albrecht William Roth (1757-1834) who published an account of 200 of them in Novae plantarum species praesertium Indiae Orientalis', from Berlin in 1821. In 1814, in keeping with the general trend of officers serving in India, Heyne published his Tracts, historical and statistical, on India. Though much of the material in the book is of a scientific nature, there is a mandatory essay 'On the propagation of the Christian religion in India, and on the moral character of the Hindoos'.

There were two little-known short-term successors to Heyne. William Sommerville Mitchell held the appointment for less than two months October-November 1819 followed by George Hyne (1800-1826) who remained in office January - June 1821. His successor's name James 'formerly of Madeira', was appointed assistant surgeon on 14 June 1821 and botanist a year later, on 12 July 1822. Shortly after Klein's death, Shuter officially bought his collection from his estate. He returned to England on sick leave in January 1826, but died on 12 October 1826. While in office, Shuter prepared a vegetable materia medica which the Madras Governor Sir Thomas Munro presented to the University of Edinburgh in 1826. On a personal level, Shuter on his visit home took with him a collection made for the Glasgow University botany professor William Jackson Hooker (1785-1865). We thus see that even when an India-based European naturalist was rather mediocre, he was of great use to European naturalists.

Robert Wight (1796-1872): Shuter's successor, Robert Wight (1796-1872), was a botanist of great fame. He was the last one to hold the Madras naturalist's post and saw the focus shift from scientific botany to the economic. Unlike many surgeons in India, Wight came after obtaining his M. D. Coming from a well-connected Scottish family which had seen better days, Wight was educated at Edinburgh University, where in 1818 he wrote a 14-page dissertation in Latin with the translated title On the nature of fevers dissected with a scalpel. It is said that he joined a ship as a surgeon and made many voyages including one to America. It is not clear when this was done. He came to Madras in 1819 as an assistant surgeon in a regiment of which his elder brother James subsequently became a colonel. Wight had had no particular training in botany. Earlier botanists were all gone so that there was no one to induct him into the discipline. He educated himself with the help of books which he managed to obtain: Willdenow's Species Plantarum (published 1797-1806), Persoon's Synopsis (1805-1807), and Lichfield's translation of Linnaeus' Genera Plantarum (1787). Wight hired local plant collectors and set out to prepare specimens.

In 1823 he sent a collection to Dr Robert Graham , professor of botany at Edinburgh who however did not respond. It has been defensively said that the consignment was lost on sea but the fact of the matter is that Graham did get the specimens but chose to ignore them.

The Madras government decided to make use of his earlier anatomical training. Tipu had maintained a cattle breeding establishment named Amrit Mahal at his capital Seringapatam for military purposes. In 1824 the establishment was placed under Wight's charge. His staff comprised an Indian draftsman, two senior medical pupils and an Indian doctor. Wight however resigned the job for reasons of health, and was replaced by Dr A. E. Best. In July 1825 Wight was given a new posting, as assistant surgeon to a different regiment, but this was short lived. Next year he was appointed to the vacant post of naturalist.

In this position, he undertook a nine-month collecting tour of South India. Next, he planned an extensive two-year tour that would have taken him to 'all the richest botanic districts in the south of India including the Malabar coast'. He hoped to collect and describe as many as possible of the plants that figured in Rheede's Hortus Malabaricus, and make drawings of all the little known useful plants mentioned in Buchanan's Travels in Mysore, Malabar and Canara.

Munro's successor as Governor, Stephen Lushington, was a man of limited vision, who additionally held a personal grudge against Wight. In February 1828, the governor abolished the post of naturalist on grounds of economy, dismissed the valuable collections built over the years as mere curiosities, and dispatched them to India Office, London. Wight was sent back as surgeon to a garrison stationed in Nagapatam. Disappointed but not disheartened, he continued his botanical work in his spare time and with his own resources. The value of his work lies in the fact his field area in South India was different from the one earlier covered by Koenig and others. Wight now established a valuable collaboration with William

Hooker in Glasgow, who published his work in Botanical Miscellany during 1830-1832, and as thanks sent books to Wight in India. Wight spent three valuable years 1831-1834 in Britain on furlough, while maintaining his establishment in India. He brought with him an herbarium of 4000 species (weighing two tons), and about 100,000 specimens of plants of the presidency of Madras. He distributed his duplicates, established himself in professional circles, and initiated a very fruitful collaboration with his school and university friend George Arnott Walker(-Arnott) (1799-1868).This collaboration resulted in the publication in 1834 of Prodromus Florae Peninsulae Indiae Orientalis, containing description of plants found in peninsular India.

The Company's dispersal of plant specimens and the transfer of its herbarium to a learned body were well timed. They came at a time when the Company's 1833 Charter was under discussion. On return to India, in 1834, Wight was posted in Bellary (now in Karnataka) in a medical capacity. His regiment's march to Palamcotta, near Cape Camorin, gave Wight a chance to botanise. Finally in 1836 Wight, thanks to the Scottish network he had activated during his long furlough, was relieved of his medical duties so that he could now spend full time on botany. He was transferred to the revenue department, to 'enquire and report on the cultivation of cotton, tobacco, senna and generally of all Indian products'. The last 11 years of Wight's Madras career, 1842-1853, were spent working on cotton at Coimbatore. The work on economic plants so far had focused on Indian species. But now the plan was to introduce new varieties from US and export raw material to by now industrialized Europe. The project was more or less a costly failure, but it does tell us about the British priorities of the time.

Once freed from his peripatetic medical duties, Wight mastered the art of lithography and set out to publish illustrations of his plant specimens. He simultaneously began work in 1838 on the hand-coloured Illustrations of Indian Botany and the un-coloured Icones Plantarum Indiae Orientalis. The Icones, carrying a total of 2101 un-coloured plates were published in six volumes over an extended period of 15 years, 1838-1853. The government partially subsidized the enterprise by order 50 copies of each publication. Wight selected about 200 Nilgiri plants from his Icones, had them coloured and issued as Spicilegium Nielgherrense (1846-1851).

3.1.5. Zoology

Zoology was a late starter in British India, because animals had no commercial value. Academic studies could not take place early because of the known aversion of Sir William Jones, the founder of the Asiatick Society. In his tenth anniversary discourse in 1793, he famously expressed himself in poetic language : 'Could the figure, instincts, and qualities of birds, beasts, insects, reptiles, and fish be ascertained either on the plan of BUFFON, or on that of LINNEUS, without giving pain to the objects of our examination, few studies would afford us more solid instruction or more exquisite delight; but I never could learn by what right, nor conceive with what feelings, a naturalist can occasion the misery of an innocent bird and leave its young, perhaps, to perish in a cold nest, because it has gay plumage and has never been accurately delineated, or deprive even a butterfly of its natural enjoyments, because it has the misfortune to be rare or beautiful''. In 1796, two years after Jones' death, the Society announced their intention of establishing a natural history museum and invited donations. It was however only in 1814, that contributions of animals, plants, minerals, etc., were solicited, and arrangement made for their reception. In 1837, Dr J. T. Pearson of Bengal Medical Service was appointed to look after the Museum.

Two years later, in 1839, the Court of Directors sanctioned a grant for the Museum. In 1841 Edward Blyth (1810-1873) was brought from England as the curator. He remained in office till 1863 when he returned to England due to ill health. In spite of drudgery of his routine work and unpleasant disputes within his employers, Blyth built up the museum and emerged as an authority on Indian and Burmese birds. In 1888, he was described as the Father of Indian Ornithology. He became an acclaimed expert on Indian fauna and domesticated animals, and was Charles Darwin's informant on these for 15 years.

Like many others, Blyth turned towards India because of poverty. Unlike others, however, he remained poor. His salary was low to begin with, and remained stagnant throughout. From 1844 he indulged in the ethically dubious but then normal two-way trade of live animals. He even tried to strike a deal with Darwin and John Gould. They declined, but significantly, there was no sense of outrage. Blyth arranged to supply to England animals which were in demand there for private and public zoos. Similarly he imported live animals into India; 'Natives of enormous wealth are the purchasers, who care not what they give for what they particularly fancy.' A particularly fancied import item for the zenana was a pair of marmosets, monkeys imported from the Americas.

Thanks to Blyth's official exertions, the Museum built an impressive collection. John Anderson took over as the Curator in 1865. Next year he became the superintendent of Indian Museum which was founded using the Asiatic Society Museum collection as its nucleus. In 1891 Botanical Survey of India was constituted but by this time the best in colonial field science was already over. Further, in 1916, the anthropological and zoological sections of the Museum were made into Zoological Survey of India, a step of administrative significance rather than scientific.

3.1.6. Agriculture and animal husbandry

Farming and animal husbandry were the two most important economic activities in India. The colonial government's interests in them were however selective and self-centred. In agriculture, it was interested only in exports, but for administrative reasons it wished to avoid famines. From among the animals, for a long time, its attention was focused on the horse which was required for service in the military. An army stud department was established in Bengal as early as 1779, and a horse breeding farm was established in 1784 in a vast 1350-acre estate near a village called Pusa in Bihar. In 1808, the charge was handed over to a well-regarded English veterinarian, William Moorcroft (1767-1825), better known as a geographical explorer. The farm was closed in 1874.

We have already noticed how the pre-existing Amrit Mahal cattle breeding establishment in Mysore was taken over by Madras government in 1813 for research on pack animals for the army. Developments in Europe forced a look at cattle in general. Influenced by the severe cattle plague (rinderpest) epidemic in Britain during 1865-1867, an Indian Cattle Plague Commission was set up in 1869 under the chairmanship of Colonel John Herbert Brockencote Hallen (1829-1901), principal veterinary surgeon in Bombay army. On its recommendation, an Imperial Bacteriological Laboratory was established in Poona in 1890, and Dr Alfred Lingard appointed its head. Typically, for some years, Lingard worked mainly on investigations of surra in horses. On his recommendation, the Laboratory was shifted to Muktesar in Kumaon hills in 1893. For sustained activity during winter months, a branch was opened in the plains, in Izatnagar in Bareilly district. The name was changed to a more impressive Imperial Veterinary Research Institute in 1925.

Agriculture was a low priority area for colonial India. The British interest in Indian agriculture primarily focused on industrial cash crops. An agricultural department was established in 1871 'chiefly in relation to the supply of cotton from India'. The department was however declared to be a failure and closed in 1878. The Famine Commissioners in 1880 strongly recommended creation of agricultural departments in all provinces. These departments would inform the government of 'approach of famines', suggest measures for their prevention in future and take charge of operations in case of an actual famine. Accordingly a central agriculture department was set up afresh in 1881. Agricultural research began as late as 1905 on the personal initiative of the Viceroy Lord Curzon, when an institute was established in the Pusa estate. Significantly funding for it did not come from the government but from an American philanthropist Henry Phipps through the family connections of the Viceroy's wife.

3.1.7. Indians on the periphery

Collection of plants from the field, preparation of specimens and drawing their sketches were important parts of a European naturalist's project. These tasks were entrusted to the Indians. To retain ownership of drawings and specimens, the part-time naturalists preferred to pay their staff from their own pocket rather than bill the Company, as was done by Buchanan and Roxburgh to their disadvantage. To protect the specimens and the paper on which they were preserved from attacks by the ants, the feet of the wooden cabinets were kept immersed in troughs of water. To replenish the water lost by evaporation, a person was hired whose job was to keep the troughs filled with water 'until the shadows of evening came on'.

Calcutta Garden did have artists on its staff. Many Europeans did not bother to record the names of the artists working for them. In other cases, we know the names but nothing else. To our frustration, but not surprisingly, none of the Indians so employed seems to have left behind any account. Indians who first took to sketching the flora under the watchful European eye came from families with painting tradition. In recent times, there has been interest in examining how these artists' work represents a combination of two distinct traditions. Towards this end, bits and pieces of scattered information have been collected and attempts made to create a contextual account. In his 27 years of career in Madras Presidency, Wight employed two Telugu artists. Rungiah worked from Wight's arrival in 1826 till 1845 and the former's pupil Govindoo from 1845 till Wight's retirement in 1853. Rungiah was taught the use of microscope by William Griffith. Wight even immortalized Govindoo in the generic name Govindooia. Rungiah might have served Wight's predecessors as well, and Govindoo continued to work post-Wight at Madras for Hugh Cleghorn and Richard Henry Beddone (1830-1911). Note that only their first names are on record. Rungiah belonged to the Raju community; Govindoo was probably related to him. There is indirect evidence to suggest that their forefathers had worked for the rajas of Tanjore. It has been speculated whether the early South Indian flora painters transferred from textile or mica painting to European natural history. The artists in North India came from the royal court tradition rather than the temple. A painter notable for his versatility, is Lutchman Singh or Lakshman Singh who was employed in Calcutta garden. He painted a portrait of George Potter in the 'Murshidabad style' in 1828, when Wallich was away to Europe. His services were borrowed by Royle in Saharanpur where he made three zoological drawings. Interestingly, Lachhman Singh 'decamped for a spell to work as a Court painter in one of the Punjab hill states'.

But, once the new art of lithography was introduced, talented persons who had no previous connection with painting could become professionals. This was part of a broader phenomenon. The traditional caste profession equation underwent a significant transformation. Old professions which were learnt through apprenticeship remained the preserve of the associated caste as before. But if a professions was taught in the educational institutions, it got decoupled from caste. Newly introduced professions by definition had no caste connotation and could be adopted by any one.

3.1.8. Discussion

When the British East India Company was established modern science had not yet come into existence. The making of a scientific and industrial Europe took place in three ways. First, concerted efforts to decrease the human cost of the voyages and make navigation safe brought about advances in astronomical and related sciences. Secondly, the introduction of natural produce-based processes and empirical technologies from Asia inspired Europe to take up industrial and scientific research which led to the industrial revolution. Thirdly, Europe was introduced to nature in its full global diversity and glory.

Systematization of natural history knowledge remained consistently high on Europe's agenda. The development of physical sciences was strictly an internal matter of Europe while industrial activity required only initial inputs from outside. But natural history required continuous interaction with distant lands and their people. Whatever science could be done in Europe was carried out there; there was no need to take it to the colonies. Thus physics never became a part of colonial science in India. A small exception had to be made in the case of chemistry because it was required as an administrative aid. A fairly well equipped chemistry laboratory was set up in the Presidency College Calcutta in 1874. One of the first experiments the newly arrived chemistry professor Alexander Pedler (1849-1918) was asked to do dealt with the chemical analysis of the cobra poison with a view to finding effective antidotes. His citation for election to the fellowship of the Royal Society in 1892 mentions this work as also the one on Calcutta's water supply.

The same college's Indian physics professor Jagadis Chunder Bose (1858-1937) won international acclaim for his pioneering experimental work on short radio waves begun in 1895. Interestingly, this personal work was fashioned by Bengal's climate. Europe was happy to work with metal to make radio detectors and receivers. But since metal rusts in the damp climate of Bengal, Bose experimented with a whole new class of 'natural substances' including even jute. His work on galena crystal has especially been of great intrinsic value to the world of science.

Colonial science was a complex and multi-dimensional phenomenon. A number of questions have been asked and addressed variously. What were the Company's requirements and what were the European demands on it in the field of science? How did the European men of science in India conduct themselves? What was their self-perception and how were they viewed and treated by European savants? Where did the Indians stand in the colonial scheme of things?

The British-sponsored science by the very reason of its existence was field science. Geography, geodesy, geology, botany, zoology, paleontology, archaeology, medicine and even astronomy-all these stemmed from the physical and cultural novelty of India. British rulers were not interested in science in India for its own sake, but in using it to further their interests. Whenever their practical needs pointed a finger towards a particular branch of science, attention was paid to that science. Harnessing science advances it also. Thus in the process of empire building, India was added as a field station to the edifice of world science. Europe's centrality in science was discipline-specific. It arose from the accomplishments in physics and chemistry and technologies based on them. It did not extend to botany and zoology. The naturalist in the colonies no doubt looked up to Europe for guidance, help, appreciation and recognition but at the same time viewed himself as a pioneer researcher or a collaborator rather than asubordinate.

Within natural history, rocks stood apart from plants and animals. Geology was seen as intimately connected with mining. The Company did not want any European involvement in mining. On their part, the British mining and manufacturing interests viewed India as a profitable captive market and did not want any competition emerging from within India. Consequently, the mining and prospecting rules in operation throughout the 19th century were so designed as to make it impossible for anyone to break the Company monopoly on mining. It is only when Germany and Belgium snatched the Indian iron and steel market from the British that the latter liberalized their mining policy in India on the principle that if Britain was not going to sell its iron and steel to India, it could as well permit India to make them. This is how Jamsetji Nusserwanji Tata was able to establish an iron and steel mill in what was later named Jamshedpur.

While geology could be pursued only as a large-scale labour-intensive organized enterprise, in the case of botany the medical, exotic, aesthetic, commercial and scientific aspects all combined in a seamless fashion. It is remarkable that scientific botany was initiated in India not by merchants but by missionaries. who remained particularly active for half a century, from Koenig's arrival in 1768 till Rottler's death in 1836. Sent out to spread the Gospel, the missionaries were ready to live a life of poverty. They had the linguistic ability to interact with the local population as also the intellectual capability, training, discipline, time and contacts with European academe to carry out high-quality natural history studies. One wonders what course colonial botany would have taken if it had not been preceded by missionary botany. Most Company naturalists in India were doctors trained in Scottish and Irish medical schools. Many left their studies half way as soon as they found employment while a few came after obtaining their degrees or returned to do so. Service in India not only made them personally wealthy but also helped them gain social and professional recognition back home.

Since the number of Europeans in India was small, merit and usefulness came to transform the social dynamics. Mathematically gifted Reuben Burrow who in England was considered low-bred could in Calcutta count a supreme court judge (Sir William Jones) as his personal friend. Colonial service was a great social equalizer. A man born to extremely poor parents (William Lambton) could tutor and make friends with a French nobleman (John Warren). Colonial service and scientific accomplishments remove the stigma of illegitimate birth innthe case of m Roxburgh. Lambton's teacher the 18th century eccentric English mathematician William Emerson (1701-1782) refused the offer of fellowship of the Royal Society because it cost too much. But, for the colonies- returned, 50 pounds as a fee for joining the Society represented upward social movement. It was a commonplace for officials in India to write their memoirs or tracts to be able to earn the label 'well-versed in oriental curiosities'.

India offered such wonderful opportunities for scientific exploration that even those European officials who may not have come to much had they remained in Europe were transformed into respectable scientists. Even when their contribution to science was not great they served the cause of their country well. Falconer could become the director of a botanic garden at the young age of 23, and conduct post mortem of wild animals to understand the better the fossils he had unearthed. Opportunity to build a personal fortune, obtain professional recognition and achieve a higher social status back home all acted as powerful incentives for conducting natural history researches beyond the call of official duty. European men engaged in scientific pursuits in India sought recognition in Europe which was not always forthcoming. There was a common complaint that science big wigs in Britain did not even acknowledge letters leave aside appreciate the work. Wight got the same treatment from Graham at Edinburgh but was able to establish an excellent equation with William Hooker at Glasgow who received specimens from Wight and sent him books in return. Interestingly, for three years the British publications gave his first name wrongly, as Richard. Obviously, the name of a European labouring in a far-off colony did not quite matter in Europe's own circles.

While the European naturalists in India were happy with the material they had at hand they were acutely conscious of their intellectual isolation, non-access to published works and lack of opportunity to interact with 'living authorities'. Arnold makes this point convincingly but he overstates his case and over-reads the evidence. When Charles Lyell complimented the Wollaston medallists Falconer and Cautley on the manner in which they overcame their disadvantages, Arnold would like to believe that Lyell was imputing that 'science in the colonies was inevitably a more amateurish pursuit than in the metropole'. Similarly, he asserts that 'Even those who gained a reputation outside India-such as Falconer, Everest and the surgeon-botanist J. Forbes Royle- felt like novices when they first ventured into scientific circles in Britain'.

3.1.9. Company as a reluctant patron of science

Just as evangelicals in Britain wanted the Company's help in spreading the Gospel in its territories, the British men of science wanted the Company to lend its support in advancing science. Both were disappointed; the former fully, the latter partially. The Company knew the value of science and pressed it into service whenever the need arose. It however was extremely reluctant to support science for its own sake. Yet the Company though powerful had its limitations and compulsions. It was answerable to the parliament, subject to government control and sensitive to home public opinion. As a result, a small amount of noblesse oblige was thrust upon it. As science progressed in Europe and scientific community became visible and influential the merchant rulers were forced to pay homage to science, but only to a point. The Company did sponsor the publication of Roxburgh's lavishly produced three-volume Flora of the Coromandel Coast 1795-1819, but the failure to recover the costs put a stop to such extravagance

.Yielding to appeals by the scientific community, the Company permitted Hugh Falconer to remain on full salary in London from 1844 till 1847 to work on the Shivalik fossils, but then brought him back under threat of forfeiture of pension. The work was finally published in the post-Company period, in 1868. Similarly, in 1851 notwithstanding a memorandum from the British Association, the Company refused to promote a project on Flora Indica by Joseph Dalton Hooker and his collaborator Thomas Thomson (1817-78), later the superintendent of Calcutta Garden 1854-61. After the demise of the Company rule 'the scantiness of the encouragement given by the East India Company towards the development of natural history of this great country' was taken note of and steps taken 'to redeem India from this disgrace'. Finally Hooker's monumental seven -volume Flora of British India was published 1875- 1897 with funding from the India Office (Desmond 1992 p 194).

3.1.10. The role assigned to the Indians

The missionaries interacted with the Indians and documented their tacit knowledge with a view to incorporating it into the European mainstream. There was no question of identifying individual informants. Indians by and large remained nameless and faceless attendants in the European club of science. Whenever an Indian served particularly well credit went to his master and mentor for his success in improving the natives. There were rare exceptions to this general rule. In 1843 George Everest successfully interceded with the Court of Directors to obtain for his gifted Indian mathematical instrument maker Syed Mir Mohsin Hussain the same designation if not the same salary as his European predecessor.

When the Indian explorer Nain Singh was awarded a gold watch by the Royal Geographical Society, he was almost irrelevant at the award ceremony held in England on 25 May 1868. There was no question of his being invited to the ceremony; he was not even mentioned by name. He was the 'wily' and 'skilful ' 'Pundit employed by Captain Montgomerie', who was the real hero as far as the Geographical Society was concerned. The Pundit 'had proved himself in every way worthy of Captain Montgomerie's selection'. For this, 'tribute of gratitude and admiration' was due to him. Others before him had employed the native agency 'for the purpose of acquiring political and statistical information' but it was Montgomerie who 'discovered that they could use a sextant or a theodolite as well as Europeans. That was really a most valuable discovery.' Hope was expressed that further explorations would be carried out by 'native enterprise directed by English intelligence'.

In the same vein Falconer's 1868 biographer Murchison smugly noted that 'the intelligence, docility, and exquisite manual dexterity of the natives' when 'backed by their faith in the guiding head of the European' 'furnished an inexhaustible fund of resource'. Probably the most trivial duty assigned to Indians in the cause of natural history was at Botanic Garden Calcutta. To prevent the ants from eating the specimens and the paper on which they were glued the feet of the cabinet were kept immersed in troughs of water. To replenish the water lost by evaporation, Wallich hired a person to keep the troughs filled with water until the shadows of evening came on and relieved him from his tedious and monotonous task. The most creative use of the locals was in painting natural history specimens. As already discussed the court tradition in north India and the temple tradition in south India were combined with European requirements to give rise to a unique style which is of interest not only to students of natural history but also art history.

3.1.11. Conclusion

Early use of modern science in India was sporadic and desultory, and motivated by localized curiosity. Most of it had no contemporaneous significance and was incorporated into the main body of science much later. Additionally, it left the Indians themselves untouched. The British-sponsored science by the very reason of its existence was field science. Geography, geodesy, geology, botany, zoology, paleontology, archaeology, medicine and even astronomy-all these stemmed from the physical and cultural novelty of India. British rulers were not interested in science in India for its own sake, but in using it to further their interests. Whenever their practical needs pointed a finger towards a particular branch of science, attention was paid to that science. Harnessing science advances it also. Thus in the process of empire building, India was added as a field station to the edifice of world science. Astronomy was the first modern science to be brought to India, as a geographical and navigational aid. Physical science was never a part of colonial science. The missionaries interacted with the Indians and documented their tacit knowledge with a view to incorporating it into the European mainstream. There was no question of identifying individual informants. Indians by and large remained nameless and faceless attendants in the European club of science.

3.1.12. Summary

- *Early use of modern science in India was sporadic and desultory, and motivated by localized curiosity. Most of it had no contemporaneous significance and was incorporated into the main body of science much later. Additionally, it left the Indians themselves untouched.*
- *British rulers were not interested in science in India for its own sake, but in using it to further their interests. Whenever their practical needs pointed a finger towards a particular branch of science, attention was paid to that science.*
- *The 1757 battle of Plassey laid the foundation of the British colonial empire and also science was now pressed into the cause of empire-building and institutionalized.*

- *Astronomy was the first modern science to be brought to India, as a geographical and navigational aid. Its early use was however sporadic and mostly out of personal curiosity.*
- *Surveys were continually required for military purposes. Geographical location of important places in the country was determined with alacrity by 'borrowing a sextant here, a watch there, and a quadrant in another quarter, from different officers at Calcutta who happened to possess them'.*
- *Systematic study of botany in India was pioneered by John Gerald Koenig, a native of the Baltic province of Courland, who came to the Danish settlement at Tranquebar near Madras. In 1891 Botanical Survey of India was constituted.*
- *The British desire for exploration and increased revenue led to the epoch- making discovery of fossil fauna in the Shivalik hills.*
- *European access to India was a multi-dimensional phenomenon. Europe was excited about the opportunities that the vast landmass of India offered in natural history studies. European interest in their field work brought them scientific recognition as well as the much needed cash. More significantly, they introduced the colonial administrators, especially the medical men, to systematic botany.*
- *Farming and animal husbandry were the two most important economic activities in India. The colonial government's interests in them were however selective and self-centred. In agriculture, it was interested only in exports, but for administrative reasons it wished to avoid famines. From among the animals, for a long time, its attention was focused on the horse which was required for service in the military.*
- *Physics never became a part of colonial science in India. A small exception had to be made in the case of chemistry because it was required as an administrative aid. A fairly well equipped chemistry laboratory was set up in the Presidency College Calcutta in 1874.*
- *In the early phase a lot of Indian were used as helper by European scientist, which result in the involvement of Indian natives in the world of modern science.*

3.1.13. Exercise

- How modern science was introduced in India by the colonial master? Discuss.
- Science was used as a tool of empire building by the European colonialist. Justify.
- Discuss the growth of various natural sciences in India during early colonial rule.
- Write an essay on the early botanical research in India.
- Give an account on the association of native Indian in the early scientific endeavor.

3.1.14. Further Readings

- Phillimore, R. H., Historical Records of the Survey of India, Dehra Dun, vols. 1-5, 1945.
- Crawford, Lt., Col D. G., A History of the Indian Medical Services, vol. I, London. 1914.
- Headrick, Daniel, R,, The Tools of Empire, Oxford University Press, 1981.
- Bose, P. N,, in Centenary Review of Asiatic Society of Bengal, 1885.
- Burkill, I.H ., Chapters on the history of botany in India, Calcutta: Botanical Survey of India, 1965.
- Crawford, D.G., A history of the Indian medical service 1600-1913 , 2 vols, London: W. Thacker and Co. , 1914.
- Desmond, R., The European discovery of the Indian flora, New York: OUP, 1992.
- Headrick, D. R., The tools of empire: technology and European imperialism in the nineteenth century, Oxford University Press, 1981.
- Kochhar, R ., Science in British India. I. Colonial tool. Current Science, 63 689-694, 1992.
- Kumar, D., Patterns of colonial science in India. Indian Journal of History of Science 15(1) 105-113 Kumar D 1995 Science and the Raj, Delhi: OUP, 1980.

*****

Unit-3

Chapter-II

INDIAN RESPONSE TO NEW SCIENTIFIC KNOWLEDGE.

Science and Technology in Modern India

Structure

3.2.0. Objectives

In this lesson, students explore the introduction of history of modern sciences in India and their response by Indian. After completing this chapter, you will be able to:

- *trace the history of association of Indian in early scientific activities in colonial India;*
- *identify the various stages of response of Indian scientist to the introduction of modern sciences in India;*
- *recognize the contribution early scientists in India and their role in nation buildings;*
- *appreciate the role of Indian sciences in the independent India .*

3.2.1. Introduction

Previous chapter discuss the advent and growth of modern science in India under the colonial rule. We come to know that in early period science was used by the British to promote their colonial interests. This chapter will discuss the involvement of Indians in the faculty of sciences, where the natives were trained and hired to provide assistance to the government science machinery; and the Indian-response stage, in which Indians took to scientific research on their own initiative. Here we use the term native to refer to Indians in a subservient role.

3.2.2. Involvement of Indian in Early Scientific development.

The moonshee phase: Just as the British in India needed science, they needed Indians also. The first task assigned to the natives was to educate the foreigners about the lay of the land, without which knowledge their military might would be useless. In 1774 'Golam Mohamad, a Sepoy Officer' was sent 'to explore the roads and countries of the Deccan' and 'to gain intelligence about the Mahratta powers'. In the 1780s, Thomas Call, Surveyor-General of Bengal, while working on his Atlas of India employed 'Munshys to survey some roads between places well ascertained in the Map' and procure 'some very useful information'. In 1791 the Bengal surveyor Reuben Burrow while budgeting for his journey asked for 'a Moonshy at Rs 25 a month. A properly instructed Indian, Mirza Mogul Beg collected data between 1786 and 1796 that went into 'A map of the countries to the West of Delhi, as far as Cabul and Multan', prepared by Francis Wilford in 1804.

The most spectacular use of the native surveyors was by Col. Charles Reynolds, Surveyor General of Bombay, who employed them for 12 years from 1795 to 1807 to collect data for a large-scale map of western India, especially of territories outside the Company's control. He even offered to pension them off on his own. As a part of this work, Reynolds discovered that Ghaggar does not cross the desert to reach the sea as had been supposed by earlier geographers, but instead loses its way in the sands near Sirsa. Reynolds received the princely sum of two lakh rupees for his valuable map.

On the other end were Company Surveyors who hired 'Native Assistants' or 'harkaras' (messengers) to do the legwork. The Company refused to reimburse these expenses. It was one thing to pay for inside information on the Mahrattas, but the Company had no intention of spending its hard earned money on such useless piece of information as that the rivers Sone and Narmada do not spring from the same place as Rennell had supposed but arose 40 miles apart. The Company not yet sure of itself was never very comfortable with the use of the Natives, which though convenient and economical, was risky. While adding to the knowledge of the Europeans they might become knowledgeable themselves, or worse, sell the information to the French or Dutch rivals. For the latter reason, half-castes were not employed. Madras Presidency solved its problem of manpower shortage in a far sighted way. Madras Observatory ran a surveying school from 1794 to 1810 to train teenager European orphaned boys as practical revenue surveyors. Note that this school was not for Indians. Those were the days-over by 1830- when the word native denoted India-born irrespective of the ethnicity. Finally in 1813, the use of harkaras for survey work was banned, 'as Government were anxious to prevent the Natives from obtaining, or being taught, any knowledge of the kind'. Only the Company's own covenanted or military officers could carry out surveying and map making. The role of the Pandits ('educated Hindus' regardless of the caste) and Munshis ('educated Muhammadans') was over for the time being.

Simultaneously, native help was commissioned to acquaint the new rulers with the people, and their customs and laws. A 'Muhammadan Madrasa' was opened at Calcutta in 1781 and a 'Sanskrit College' at the Hindu holy city of Banaras in 1791, so that bands of young Hindus and Muslims could separately collect the traditional information from their elders and pass it on to the British. Note that English was not taught at these institutions. This phase of native education in which non-English knowing Indians were pressed into service may be called 'the moonshee phase', advisedly using the old spellings to underline the intended meaning.

Baboo phase: Once the East India Company became a ruling power, the question of English education for the natives was bound to arise. With the final defeat of the Mahrattas in 1817-18, the British hold on India became complete and unassailable, and the British could afford to relax. The Governor-General, Lord Hastings, could now loftily announce that the Government did not consider it necessary to keep the Natives in a state of ignorance in order to retain its own power. As a matter of fact, services of Indians were now required in running the administration. This was the beginning of what we may call the 'baboo phase' of native education under British auspices. As befits a cautious and clever ruler the transition from the moonshee phase to the baboo phase was to be effected in an unobtrusive manner, and with the full and active support of the native leadership. On 20 January 1817, Hindu College was 'opened at Calcutta. Its prime mover was Raja Ram Mohun Roy (1772-1833), who however kept out of the picture for fear of 'alarming the prejudices of his orthodox countrymen.' Earlier the Company had hired Hindu and Muslim boys to attend oriental colleges. Now, upper-class Hindu boys paid from their own pocket to receive English education. The college started receiving Government grant in 1824, and science classes were started. (Finally in 1855 Hindu College was converted into government-owned Presidency College.) Once the British supremacy was established and survey work expanded, need for involving the Indians themselves was increasingly felt. After all, you cannot entirely dispense with the natives in their own country. A major factor in their favour was the climate: 'their service will prove of the greatest use in exploring the wilds of Bustar, etc., whose dreadful climate no European constitution could possibly sustain for any length of time'. The British surveyors naturally argued for the use of the natives: 'The advantages derived to Government are apparent opening a new field for natives, teaching them a profession hitherto unknown to them in this Presidency and allowing Government to take advantage of the cheapest agency obtaining correct surveys of the land, on which the principle revenue of the State depends" and a properly authenticated survey, so necessary to the due administration of justice'.

The policy found support at the highest level. In 1829, Lord William Bentinck, Governor-General of India. wrote in a minute on the organization of the survey: It is by a more enlarged employment of native agency that the business of a Government will be at once more cheaply and efficiently transacted'. The 1830 reorganization of Survey with George Everest at the helm required immediate use of the 'native agency'. Although field data were being collected by the British surveyors themselves, they had no time to sit down and reduce the data. Arrears had in fact piled up for the previous eight years. It was therefore decided to set up a computing office as distinct from the field staff. When the Government expressed the hope that 'all requisite computers may be drawn from existing establishments under this Presidency', Hindu College was ready to fulfill it.

Offer of employment as Computers was sent to a number of students; salary was to be Rs 30 p.m. during a 6-month probation, then Rs 40. Radhanath Sickdhar and six other students of Hindu College joined at the end of 1831. Sickdhar's case is well known. Exceptionally brilliant, he was made a Sub-assistant at GTS after his probation at a salary of Rs 107 p.m. He was then 19 years old. He rose to become the Chief Computer when he was transferred to Calcutta in 1849 to hold charge of the Computing Office. He retired in 1862 and died in 1870. A bachelor, Sickdhar became thoroughly European in outlook, and began to take English food. A legend has grown that the height of Mount Everest was computed by Sickdhar. This is no doubt an attempt to push the most deserving peripheral native into a nuclear role. Unfortunately, the story is not true; the height was calculated at Dehra Dun, after Sickdhar had been posted at Calcutta.

The career-graph of other Computers is instructive. After seven years of service, six were still getting only Rs 40. Five of them quit in 1838 to accept the newly established post of Deputy Collector in the revenue department. The seventh one. Nil Comul Ghose, who was getting Rs 100 p.m., also left. The GTS. recruited another Indian, Ram Dayal De as a Sub- assistant in 1840, but dismissed him in 1844. The Surveyor-General's Office naturally took interest in science teaching at Hindu College. A European Computer and Sub-assistant, Vincent Louis Rees, was entrusted with the task of 'helping in the training of the Bengali Computers'. He also taught mathematics at Hindu College, from where he earned a salary of Rs 300 in addition to his GTS salary of Rs 318 p.m. The science teaching was apparently not substantial. Twenty years later, in 1855, Mahendralal Sircar, much interested in science, left the Presidency College to join the Medical College, saying that 'the principal object of education was to teach the pupils how to read and write the English language'.

While in general Indians were kept out of actual field survey work, there was one type of survey which they alone could do. And that was the surreptitious survey of the trans-Himalayan regions, where Europeans would have been immediately spotted and killed. This work was of great strategic importance, and necessary to fill the gap between the Indian and the Russian surveys. With characteristic British thoroughness and disdain these surveyors were only taught how to take the observations; they were not taught how to reduce the data lest they cheated. When exceptionally useful, they were rewarded with scientific medals, khitabs, and jagirs. Otherwise, even their names are not recorded; they are indicated merely by capital letters.

During the year 1876 one of the trained native explorers of the Great Trigonometrical Survey named 'the Mullah' ascended the Indus river from the point where it enters the plains of the Punjab at Attock to the point where it is joined by the Gilgit river.' In 1877, a native gentleman of the Muhammadan faith, and of much repute among his coreligionists' explored the areas beyond Hindu Kush. He was presented with one of the two medals which were placed at the disposal of the Surveyor General of India by the Venice International Geographical Congress for award to meritorious Native explorers. We do not know the name of this gold medalist, but the case of Nain Singh and Kishan Singh is well known. They were called Pandit brothers. A native officer of the Survey, Sub-surveyor Imam Baksh Bozdar took part in eight different expeditions during 25 years of his service. On his retirement in 1884 he was given a grant of 250 acres of land in the Dera Ghazi Khan district (now in Pakistan), and the title of 'Khan Bahadur'.

The establishment of astronomical observatories at Lucknow (1834), Trivandrum, and Hyderabad (1901) by Indian aristocracy also rightly belongs to the peripheral native stage, because although the ownership was Indian, the control was European. There was no attempt to introduce the Indians to modern astronomy. Lucknow Observatory closed down as soon as the instruments and novelty wore off. Trivandrum met similar fate as far as astronomy is concerned, but being close to the magnetic equator, provided valuable magnetic data. Nizamiah Observatory at Hyderabad was attached to the Osmania University and had a rather unspectacular existence. It however did participate in the international Carte du Ciel to prepare a photographic star map of the sky. Except for clandestine activities outside the boundaries of British India where ethnicity was a crucial factor, the role of Indians in the scientific pursuits remained peripheral. However, as the needs of the Empire grew so did its perception of the abilities of the natives. The scientific content of the British administration in India increased steadily; and with it increased the role assigned to the Indians. As a first step, the natives moved from being coolies to calculators. In the second, they graduated to become doctors and engineers to work on the network of railways, telegraph, roads and canals.

It is noteworthy that the first Indian fellowship of the Royal Society of London belongs to this stage. Ardaseer Cursetjee (1808-77), marine engineer at Bombay, was elected FRS on 27 May 1841. The present image of the Royal Society as a club of distinguished scientists does not go back to the early half of the 19th century when it was also a club of gentlemen 'curious in natural history', 'well acquainted with mathematics and engineering' or 'conversant in various branches of experimental philosophy'. Cursetjee belonged to the famous Parsi family of Wadia shipbuilders. Cursetjee was 'brought up and educated in the Company's service'. He was however more interested in the newly introduced steam machinery than in shipbuilding, and fortunately for him his interest converged with the Company's need. Cursetjee was requisitioned by the newly established Elphinstone Institution to teach practical sciences. The Company funded his one year visit to Britain from December 1839 to November 1840 during which he visited various royal dockyards and private foundaries. While in England, he was selected for the post of 'Chief Engineer and Inspector of Machinery in the Company's steam factory and foundary' at Bombay. His salary was to be 600 rupees a month, more than seven times his then salary as an assistant builders. Cursetjee took his appointment on 1 April 1841. He was the first native to be placed over Europeans. His staff consisted of 'one chief assistant, four European foremen, one hundred European engineers and boiler makers, and about two hundred native artificiers'.

He was elected a fellow of the Royal Society on the recommendation of James Walker, the President of the Institution of Civil Engineers. Cursetjee's certificate of nomination refers to his journey to England 'to acquaint himself with the arts and manufactures of Europe with the view of improving his own country and his countrymen', his being 'a gentleman well versed in the theory and practice of Naval Architecture and devoted to scientific pursuits'; 'and having otherwise promoted Science and the useful arts in his own country to which he has just returned'. In terms of the directions issued by the Royal Society in 1839, Cursetjee would have been classified as 'a distinguished engineer' and as 'one who is attached to science and anxious to promote its progress'. His fellowship however remained a strictly private honour. It did not advance his professional career in any planner, nor did it make any impact on his countrymens Cursetjee retired in 1857 at a specially sanctioned pension of two thirds of his salary. He died on 16 November 1877 at Richmond, England, where he had eventually settled.

The British timed their operations well. When upper Ganga canal was being dug, an engineering college was set up at Roorkee. When wood was needed for the railways, a forest school was opened at Dehra Dun. It is no wonder that the British emphasized higher education among selected Indians rather than removal of mass illiteracy, which would harm their interests. The Sahib's faith in the Baboos was fully justified. During the 1857 upheaval, it was an Indian, Seebchunder Nandy (1824-1903), who kept alive the vital telegraph link between Calcutta and Bombay. Nandy was born in a poor family in Calcutta. In 1846, he joined government service in the refinery department of the Calcutta Mint under Dr William Brooke O'Shaughnessy (1809-89) who was also the professor of chemistry at the Medical College. When in 1852, the Company authorized the construction of the first telegraph line in India under O'Shaughnessy, he placed Nandy 'in charge of the work'. It was Nandy who sent the first signal from the Diamond Harbour end of the telegraph line. The message was received at Calcutta in the presence of the Governor-General Lord Dalhousie and O'Shaughnessy. Immediately afterwards Nandy was appointed Inspector in charge of the line and entrusted with the task of training other signallars. In 1853, O'Shaughnessy became the Director-General of Telegraphy. Two Englishmen were appointed Superintendent and Assistant Superintendent, but Nandy continued as Inspector. Nandy became Assistant Superintendent in 1866, retired on special pension in 1884 when he was made Honorary Magistrate. On 28 February 1883, he was made Rai Bahadur. He died of plague on 6 April 1903 during the Calcutta epidemic. Note that while the Government kept him in his place in its hierarchy, he was given honours which will raise him in his social hierarchy. Interestingly, on retirement Nandy changed the spellings of his name from the anglicized Seebchunder to the phonetically more correct Sib Chandra. When the Calcutta corporation decided to name a lane in his honour, it bypassed the problem of the spellings by opting for the colloquial Sibu Nandy.

Even in the post-independence India, the harnessing of the natives by the colonial Government has not been a topic of much comment. An official history of Indian telegraph' written by Krishnalal Shridhami in 1953 gushes about Nandy's role in the first telegraph line: 'History was made with an Indian at one end of the line and an Englishman and Irishman at the other'. The incongruity of this can be seen from an imperialist comment on what the Indians prefer to call the First War of Independence. Sir John Laird Mair Lawrence (1811-79) who as Chief Commissioner ‘saved Punjab’ during the mutiny and later (1864-69) served as Viceroy of India said The telegraph saved India’. If the Mutiny had come 10 years previously when the railways and the telegraph had not yet been introduced it might have succeeded.

The simultaneous use by the British of science as well as the natives brought the two into contact. This point is tellingly brought out by the contrasting case of two 19th century Indian astronomers. Samanta Chandrasekhar (1835-1904) was born in the small village Khandpara, some 50 to 60 miles west of Cuttack. The only astronomy he could learn was the pre-telescopic one. Following in the footsteps of Bhaskara (b. AD 1114) and using primitive instruments he completed at the age of 30 his Siddhanta Darpana, containing 2500 Sanskrit shlokas of various metres, including some of his own composition. He was looked down upon by his kshatriya clansmen, including his nephew, the King, for taking to a brahmanical profession. The Raja of Puri bestowed on him the title Harichandana Mahapatra. In 1893 the Viceroy issued a Sananda conferring on him the title of Mahamahopadhyaya, a title normally reserved for Brahmins. A year before his death, he was sanctioned a monthly pension of Rs 50 ‘in view of the high social position of the Mahamahopadhyaya’, with the Viceroy explaining to the Secretary of States for India. ‘the case being a curious and interesting one of devotion to learning for its own sake, and the Lieutenant-Governor believes that Government in honouring such a student will honour itself.’ ‘the grant of a pension to such a student would be entirely in consonance with native feeling’ ‘we regard the Pandit’s work as no means devoid of interest, and even value since it throws light upon the beginning of Astronomy, by showing what can be done by primitive instruments’.

In later years, Samanta Chandrasekhar did see through a telescope, and bitterly regretted that he had not had the advantage of such an instrument in his younger days. In sharp contrast stands the case of Chintamani Ragoonatha Charry (1828- 80), who was the son of an Assistant at the Madras Observatory. Joining the Observatory as a daily-wager when still a teenager, he rose to become the First Assistant with a monthly salary of Rs 150. His 1867 discovery of a variable star R Reticuli is the first recorded discovery by an Indian; this earned him the fellowship of the Royal Astronomical Society. He set out to update the elements of traditional panchangs. He compiled a work in Tamil entitled Jyotisha Chintamani (he did not know Sanskrit). He also published an almanac Drigganita Panchanga with the help of the Nautical Almanac. Charry gave public lectures on astronomy and brought out a book on the 1874 transit of Venus. This book explains the phenomenon by a dialogue between a Pandit and a Siddhanti (an astronomer). Originally written in Tamil, it was translated into English and other local languages including Urdu. It was only natural that while serving- the scientific interests of the British, the Indians should think of responding to science on their own.

3.2.3. The Indian-response stage

India had been a fabled country; its subjugation was seen as a proof of the superiority of the British way of life. The British, therefore, set out to impress their values upon the Indians. There were practical considerations too. India was already a thickly populated country, where permanent white settlements were out of question. And after the disastrous Portuguese experience, Britain had no intention of producing a nation of half-castes. It was, therefore, essential to involve Indians in the task of ruling over India. Thus inherent in the British rule was the preparation of Indians to eventually overthrow that rule. The preparation, slow as it was, started quite early. In 1774, the Company established a Supreme Court of Justice at Calcutta. It was a revolutionary concept. For the first time in the history of India, there was now a framework of law which did not depend upon the personality of the ruler. Indian lawyers would provide valuable leadership in the years to come. The off-shoot of the introduction of judiciary was even more momentous. It became essential for the Company to familiarize itself with the Hindu as well as Muslim law. A digest of Hindu law was got prepared from the Pandits, but no one could be found to translate it from Sanskrit into English. It was, therefore, first translated into Persian and then into English. It was thus clear that Sanskrit was not an entirely dead language; it had a utility value also". This convergence of the practical need of the Company and the scholarship of Sir William Jones brought about the all-European Asiatic Society in 1784, which initiated researches into Indology.

Moreover, European men of science were fascinated by the mastery of the Pandits in preparing astronomical almanacs even without knowing the why of it. As early as 1687, a Frenchman Simon de La Loubere (1642-1729) who had gone to Siam (Thailand) as an envoy of the King of France brought back a set of 'Hindu Mathematical Tables' which 'passed from hand to hand as a sort of historic curiosity until they were explained by Cassini, one of the most eminent astronomers of his age'. John Warren (1769-1830), a former Madras Astronomer and a blue blooded French nobleman, descended from Norman the Conqueror, took up in 1811 a monumental project on south Indian systems of time-keeping. The work won approval from the Pandits who named it Kuala Sankalita, and showed their appreciation by offering to pay the expenses of the wedding of Warren's daughter. Though Warren had started the work 'on a call of personal friendship', Madras Government decided to fund it for its practical value. It was felt that the work will make Indian calendars intelligible to the Europeans, facilitate a comparison of the European and Indian chronologies and thus be 'of service to gentlemen employed in the Revenue and Judicial departments'.

3.2.3.1. Initiation of Indian Response

European interest in India's antiquity had far-reaching influence on the Hindus. The discovery of their past glory, as certified by the Europeans themselves, restored the sense of self-esteem of the Hindus and gave them the courage to look the Empire right into the eye. During the first 100 years of their lordship over India, the British introduced the Indians to the English language and literature; to western thought; to India's glorious past; and to modern science and education. It was now for the Indians to prove, to themselves more than to anybody else, that they as the inheritors of a great civilization were capable of becoming full-fledged members of the world's science club.

3.2.3.2. Ramachandra and Indian Mathematics

The very first case of Indian response to modern science came not from intellectually active Calcutta but from still-Mughal Delhi. Unlike Calcutta, Delhi had shown no interest in English education. The government therefore decided in 1843 to introduce education through the medium of the vernacular language'. Ramchandra (1821-80) born in a respectable but impoverished 'Hindu Kayasth' family 'maintained himself by winning scholarships and prizes'. In 1844 'he was appointed a teacher of European Science in the Oriental Department of Delhi College through the medium of the vernacular'. In 1850 he published in Calcutta his mathematical work Problems of Maxima and Minima, which though criticized in Calcutta Review, was well received in Europe thanks to the efforts of India-born famous English mathematician Augustus de Morgan. Morgan saw in it 'merit of a peculiar kind, the encouragement of which was likely to promote native effort towards the restoration of the native mind in India'. Accordingly the Court of the Directors sponsored in 1859 a reprint of this work in England for circulation in Europe and in India. 'Also the Honourable Members of the Court of Directors were pleased to sanction a khillut (dress of honour) of five pieces to be presented to him and also a reward of Rs 2000. Ramchandra's response was typical "I am much thankful to the English Government that they are so bent upon encouraging science and knowledge among the natives of this country, as to take notice of a poor native of Delhi like myself". Ramachandra's second book A New Method of the Differential Calculus appeared in 1861. In 1858 'after the Mutiny had subsided' Ramchandra was appointed teacher of mathematics in the Government Engineering College Roorkee, and about the end of the same year, headmaster of the newly established school at Delhi. In 1863 he was appointed tutor to the Maharaja of Patiala, where he also served as the Director of the newly established Department of Public Instruction. He died in the month of August 1880.

In spite of his own achievements, he can hardly have been a role model for his country-men. The contemporaneous impact of Ramchandra, in the pre-mutiny Delhi came not because of his Urdu writings or mathematics, but because of his conversion to Christianity in March 1852, for which he had to leave his mother, wife, children and brothers and meet with great opposition from his caste men, his name was held up for a warning as to what results might happen if the English language were allowed to be taught to the young'. Ramchandra barely escaped the wrath of the 'mutineers' thanks to the timely help given by his pupils. Dr Chaman Lal, a fellow Christian, was however not so lucky. He lost his life.

3.2.3.3. Industrial Art Society and R.L.Mitra

It became clear to the Indian opinion makers quite early in the game that the English education being imparted to them was inadequate. Thus The Hindu Patriot wrote on 6 April 1854 '… The end aim of their education is to make them either accountants or letter writers …. The resources of the country will never be developed unless the children of the soil learn to develop them'. The role of science as a social reformer was also noted.

Rajendralal Mitra (1829-91), who later became the first Indian President of the Asiatic Society, wrote in 1854 that 'practical training will be an effectual means for the removal of those barriers to progress which have been created by the ancient system of confining the cultivation of industrial art to particular classes, and those the least educated in the community'. Mitra had just established an Industrial Art Society where the Indians could learn practical skills'. Here was thus an attempt to create an Indian infrastructure of science parallel to that of British India. Such attempts were few, half-hearted, and ineffectual.

3.2.3.4. The Indian Association for the Cultivation of Science

The Bengalis believed that since they knew Shakespeare as well as, if not better than, the British themselves, their edifice of science should be an extension of, and supported by, the British effort. 'Science application' was to be left to the Government: it was 'science speculation' that needed cultivation. The leadership came from Dr. Mahendralal Sircar (1833-1904), a poor orphan, who owed his station in life to western education. The object of Dr. Sircar was not to establish a technical seminary and thus make his countrymen a nation of artisans and mechanics, but to diffuse among them the ascertained principles of Western Science in the hope that after mastering what had already been discovered by the Europeans, the Hindus might, in course of time, add their own discoveries to those of their fellow brethren of the West'. Sircar was a man of strong convictions and tenacity. An M D from Calcutta Medical College, he had the courage to face professional ostracism for his advocacy and practice of homeopathy. In 1869 Sircar came up with the idea 'of a national institution for the cultivation of science by the natives of India', and enlisted the support of Sir Richard Temple, the lieutenant-governor of Bengal during 1874-77 and a 'man of wide sympathies, deep culture and high education'. Sircar 'was Well aware that official support was the only key to unloose the purse-strings of his wealthy countrymen'. After six years of restless propaganda, Indian Association for the Cultivation of Science (IACS) was inaugurated in January 1876.

Members of the rival Indian League unsuccessfully sought the establishment of a polytechnic instead. To Sircar's great disappointment, IACS failed to materialize as a research laboratory; it remained a forum for popular and college-level lectures. In 1893 IACS was recognized by Calcutta University as a teaching centre. Two eminent scientists of the day Sir Jagdish Chandra Bose (1858-1937) and Sir Prafulla Chandra Ray (1861-1944) lectured at IACS though they carried out their research work at their own college, the Presidency College. Another visiting lecturer was Pramatha Nath Bose, a senior government geologist. P.N. Bose is a good example of the transition from the peripheral stage to the response stage.

3.2.3.5. Tata Steel Mill at Jamshedpur

On his retirement from the Geological Survey of India. P.N. Bose was offered appointment by the Maharaja of the mineral-rich state of Mayurbhanj: It is said that Bose educated Jamsetji Nusserwanji Tata on the iron deposits of the area. This resulted in the establishment of the Tata steel mill at Jamshedpur, in 1911.

3.2.3.6. Bombay Astrophysical Observatory

Another striking example of increasing Indian acquaintance with science is provided by Kavasji Dadabhai Naegamvala (1857-1938), a physics teacher at Government College of Science (now Engineering College) Poona. A protege of the influential British solar physicist, Sir Joseph Norman Lockyer, he was in 1888 provided with an astrophysical observatory by the Bombay government. Significantly, half of the money for the observatory came from Indian donations. Naegamvala regularly sent data to Lockyer, and records show that in 1899 Lockyer even complained to the Director of Public Instructions (E. Giles) against unsatisfactory work at Poona. Naegamvala however did make his own observations and in fact showed that Lockyer was wrong regarding his hypothesis about nebular lines in Orion. The observatory was closed down in 1912 on Naegamvala's retirement and instruments sent to Kodaikana.

3.2.3.7. Indian Institute of Science, Bangalore

Indian initiative for technical education came from Jamsetji Nusserwanji Tata (1839-1904) who himself was a product of English education and made a successful transition from trading to manufacture, becoming in 1911 the first Indian owner of a car. The Tatas set up a technical university at Bangalore, calling it Indian Institute of Science", because the word university at that time had the connotation of being no more than an examining body. The Bangalore Institute, which admitted its first students in 1911, represented the investment of 'Parsi money' for a general cause, and that too outside the Parsi mass-base of Bombay. The choice of Bangalore was made possible by the munificence of the Maharaja of Mysore whose Inspector-General of Education, Dr Hormusji Bhabha was related to the Tatas by marriage. Here, the control was British, though the students were Indian.

3.2.3.8. University College of Science and Technology: Sir Asutosh Mookerjee

While the 19th century IACS had failed to take off as a research laboratory, it came in handy for Chandrasekhara Venkata Raman (1888-1970), a teenager Indian government official, to do part-time research in physics that led to a Nobel prize. At about the same time Calcutta University was transformed into a postgraduate studies and research centre by Sir Asutosh Mookerjee (1864-1924) who was the University's honorary Vice-Chancellor during 1906-14 and 1921-23. Mookerjee was appointed a High Court Judge in 1904. He had earlier written research papers in mathematics under his pre-anglicized name, and given lectures at IACS. He turned to law only when he failed to get an appointment at IACS or at the Presidency College. As Vice-Chancellor, Justice Mookerjee persuaded, not surprisingly, wealthy lawyers to make endowments to the University for setting up (1914) University College of Science and Technology where the professorships will be held by Indians themselves. Raman resigned his government job to become a professor at the University; in the process his salary went down from Rs 1100 to Rs 600 per month.

3.2.3.9. Path breaking scientific innovation: Raman, Shah and Bose

The pinnacle of Indian response to modern science was the path-braaking work of Raman, Meghnad Saha (1893-1956), and Satyendra Nath Bose (1894-1974). It is noteworthy that none of the European professors stationed in India made any significant contribution to scientific research. Available statistics provides insight into the crucial decade of the 1920s. In the period 1920-29, a total of 19 Indians obtained doctorate in physics. Of these 19, 10 obtained their degree from Indian Universities, seven from UK, and two from Germany. In the twenties a total of 659 research papers were published, out of which only 26% were published in Indian journals. Indian scientists collected a total of 308 citations. Most came from US, followed by Germany and UK. Interestingly in the pre-Nobcl prize decade, Raman's citations (53) are slightly less than Saha's (56). Within the country, Raman got more citations, 25 as against Saha's six.

Although Indians have kept hoping for an encore, it is important to keep in mind that these spectacular achievements were made possible by a fortuitous combination of factors. Those were the days when frontline research was just a short step ahead of M.Sc level studies. Raman published his first research papers when still a student. Saha and Bose translated Einstein's German research papers on relativity for use as course material. Experimental sciences were at a stage where they required elementary infrastructural support. Industrial back up needed for researches of J.C. Bose, P.C. Ray and C.V. Raman was easily available in the country at the level of government science or college laboratories. It was science application under the aegis of the British Indian government that made science speculation by Indians possible. Finally, the take-off stage of modern physics coincided with the peaking of Indian nationalism. Science was seen by Indians as an extension of their freedom struggle. Making scientific discoveries requires a certain amount of defiance. The suppressed anger against the colonial rulers provided that defiance. Paradoxically, while Indian achievements in science were perceived as a symbol of nationalism, at the same time the honours bestowed by the colonial rulers were coveted and even flaunted.

3.2.3.10. Srinivasa Ramanujan

The most extraordinary example of Indian response to modern science is the college-dropout creative mathematical genius Srinivasa Ramanujan (1887-1920) whose introduction to modern mathematics at the age of 15 began and ended with Carr's 'Synopsis of Pure Mathematics' which a friend borrowed for him from the library of the Government College at Kumbhakonam. Fortunately, there were around men of science who had the sense to put him in touch with the mathematicians at Cambridge. One wonders as to what a Ramanujan will have done if he had been born a 100 years earlier. The fact remains that Ramanujan became a source of inspiration for all aspiring Indian scientists.

3.2.4. Scientific Innovation and Nation Building

A corollary of the science's being treated as an extension of the nationalist movement was that it was seen as a pure intellectual exercise, rather than as a means towards production of wealth. Thus J.C. Bose refused to patent his discoveries, and when patents were obtained in his name refused to en-cash them. Later when Sir Shanti Swarup Bhatnagar (1894-1955) received a large sum of money for industrial consultancy, he gave it away to his University, maintaining, in the words of his son, that 'scientific work loses its altruistic and truly cultural character if the worker becomes money- minded and begins to get financial benefits for himself. An exception to science as a cultural activity syndrome was P.C. Ray who advocated coupling of scientific research and industrial production, and himself set up a number of production units. It is interesting to note that science meant different things to different people, depending upon their social and cultural background. To Raman, born in a caste associated with learning, science was a means of establishing a gurukul on his own terms. To Saha, born in a caste considered socially backward, science was an instrument of social change. To Homi Jahangir Bhabha (1909-66), like Nehru an aristocrat by upbringing, science meant building national institutions under the auspices of independent India's government.

3.2.5. Science in Post Independent Era

Since the main purpose of history is to influence contemporary events, it may not be out of place to make some comments on the post-independence Indian response to science. One may right away enunciate a principle: The purpose of science is to produce wealth. Purpose of this wealth is to support science. A society whose economy does not depend on science cannot make a sustained contribution to science. Over the years the infrastructure required by science has moved from the level of college laboratory to sophisticated industry. A certain level of industrialization is therefore necessary to set up science laboratories, without which scientific research is not possible.

Then there is also the question of the right frame of mind. A science-dependent society is characterized by boldness, team spirit, and recognition of and reward for merit. These qualities are essential for scientific innovation. In contrast, a society whose production of wealth depends on natural elements still thinks in terms of God above and zamindar on the earth. In such a society, people are timid, afraid of new ideas and new things, obsessed with rituals rather than results, and most comfortable in a demerited patron-protege relationship. In a society that is materially semi-industrial but intellectually pre-industrial, there will not be very many chances of making scientific discoveries. Even if a discovery is staring him in the face, it will be missed by a scientist, who being a typical product of the system, is not prepared for the unprecedented. Once a while an exceptional scientist may make a major discovery. The beneficiaries of this discovery will be the nations who are already geared for it. By definition, a major discovery will take the subject fast forward, making the next break- through more difficult and less likely to arise in a semi-industrial society.

Indian perception of science has been based not on what the British did in Britain but on what the British did to India. Therefore science was not seen as a new means of production of wealth but as an agency that had destroyed traditional Indian manufacture and annihilated India's artisan classes. That is why only the speculation part of science was appreciated, while the application part was ignored. Another reason for this attitude is the fact that traditional manufacturing classes were not represented at all in the English-speaking new middle class. Winning freedom through nonviolent means has certain disadvantages. There is continuity even where discontinuity is needed. Unfortunately, even after independence, the role of science as producer of wealth was not recognized. Free India has failed to harness science. Accordingly it has failed to enrich science either.

3.2.6. Conclusion

The above discussion make us believe that the introduction and growth of modern science in India was with a view to serving the colonial interests. Thus the British-sponsored science, by the very reason of its existence, was field science. Geography, geology and geodesy, botany and zoology, archaeology, medicine and even astronomy–all these stemmed from the physical and cultural novelty of India. This science was colonial in the sense that its agenda was decided on grounds of political and commercial gain. But the studies made in India could not have been carried out any- where else. The European scientists at work in India felt and acted like pioneers in an exotic land, and were not always on the best of terms with their counterparts back home.

The role assigned to the Indians in this State science was clear cut. They were to provide cheap labour which they did most conscientiously. The Superintendent of the Geological Survey had a very low opinion of the natives. He doubted whether the natives could ever prove competent for independent field work, which required 'the very quality which more than any other makes the western man differ from the eastern'. However there was a general encouragement to the natives from the enlightened British bosses. Lambton, and then Everest, took good care of their staff. Everest got a native Syed Mir Mohsin Hussain appointed as the Head of Mathematical Instrument Department and insisted on his being given the same designation as his British predecessor, if not the same salary. The Madras Astronomer continued his chief assistant Ragoonatha Charry in service so that he could get full pension benefits.

The westernization of the Indian middle class was as much a matter of satisfaction to the British as was the physical subjugation of India. It is expected that an Empire will show some respect for the Republic of Science. When the Indians decided to do science on their own initiative, they received encouragement, if not money, from the British. Thus J.C. Bose was retired on full salary, and Raman was Knighted a full year before he got 'Nobelled'. Contrast it with the case of noted film- maker Satyajit Ray (1921-92), who was awarded Bharat Ratna by the Indian Government when he was on his death- bed and after he had received all conceivable international honours. We have distinguished here between European scientists engaged in Government science; their native scientific assistants; and the Indian scientists who were full-fledged members of the Club of Science.

3.2.7. Summary

- *Just as the British in India needed science, they needed Indians also. Thus Indian were introduced in modern science.*
- *Initially, the first task assigned to the natives was to educate the foreigners about the lay of the land, without which knowledge their military might would be useless.*
- *The Governor-General, Lord Hastings, announce that the Government did not consider it necessary to keep the Natives in a state of ignorance in order to retain its own power. As a matter of fact, services of Indians were now required in running the administration.*
- *While in general Indians were kept out of actual field survey work, there was one type of survey which they alone could do. And that was the surreptitious survey of the trans-Himalayan regions, where Europeans would have been immediately spotted and killed.*
- *The establishment of astronomical observatories at Lucknow (1834), Trivandrum, and Hyderabad (1901) by Indian aristocracy also rightly belongs to the peripheral native stage, because although the ownership was Indian, the control was European.*
- *The scientific content of the British administration in India increased steadily; and with it increased the role assigned to the Indians. As a first step, the natives moved from being coolies to calculators.*

In the second, they graduated to become doctors and engineers to work on the network of railways, telegraph, roads and canals.

- *India had been a fabled country; its subjugation was seen as a proof of the superiority of the British way of life. The British, therefore, set out to impress their values upon the Indians by introducing sciences for them.*
- *European interest in India's antiquity had far-reaching influence on the Hindus. The discovery of their past glory, as certified by the Europeans themselves, restored the sense of self-esteem of the Hindus and gave them the courage to look the Empire right into the eye.*
- *During the first 100 years of their lordship over India, the British introduced the Indians to the English language and literature; to western thought; to India's glorious past; and to modern science and education.*
- *It was now for the Indians to prove, to themselves more than to anybody else, that they as the inheritors of a great civilization were capable of becoming full-fledged members of the world's science club.*
- *Indian perception of science has been based not on what the British did in Britain but on what the British did to India. So, even after independence, the role of science as producer of wealth was not recognized. Free India has failed to harness science. Accordingly it has failed to enrich science either.*

3.2.8. Exercise

- Discuss the phase in which Indian natives were introduced to modern sciences by the colonial masters.
- Write an essay on the role played by Indian natives in early British scientific endeavor.
- Why the Colonial maters introduced sciences in late 19th century India? Discuss.
- Give an account on the Indian response to modern science in India.
- How the modern science helped the Nation building in independent India? Discuss.

3.2.9. Further Readings

- Mahmud, Syed, A History of English Education in India (1781 to 1893). Aligarh, 1895, pp. 2
- Markham, C. R,, A Memoir on the Indian Surveys, 2nd edn,, London, 1878.
- Cambridge History of India, vol.1, p. 56.
- Bose, P. N., in Centenary Review of Asiatic Society of Bengal, 1885.
- Kochhar, R. K., English education in India: Hindu anamnesis vs. Muslim torpor. Economic & Political Weekly, 1992, 27, 2009.
- Biswas, A. K., Science in India, Firma KLM, Calcutta, 1969.
- Black, C. E. D,, A Memoir on Indian Surveys 1875-1890, London, 1891.
- Sridharani, K,, Story of Indian Telegraph, P & T. Dept., New Delhi, 1953.
- Subbarayappa, B. V., in Persuit of Excellence, Tata McGraw-Hill, New Delhi. 1992.
- Kumar, Deepak (ed). Science and Empire, Anamika, New Delhi, 1991; Sangwan, Satpal, Science, Technology and Colonization, Anamika, New Delhi, 1991; Krishna, V. V., The colonial model and the emergence of national science in India 1876-1920, 1991(Preprint).

*****

Unit-3

Chapter-III

DEVELOPMENT OF RESEARCH ORGANIZATIONS LIKE CSIR AND DRDO; Establishment of Atomic Energy Commission; Launching of the space satellites

Structure

3.3.0. Objectives

In this chapter, students explore the development of research organization and their role in nation building in independent India. After completing this chapter, you will be able:

- *discuss the establishment of CSIR and its role in growth of sciences in India;*
- *analyse the role and contribution of DRDO in India;*
- *give an account of the space research in India during the running space age and*
- *understand the evolution and status of Nuclear Energy in India.*

3.3.1. Introduction

The introduction of western science in India is very recent. During the entire period of British rule, the rulers were content to have the natives only as technical assistants to their scientific explorers in this country. The British Government, while interested in creating an army of babus-the clerical staff-to assist in the day-to-day administration of the country, were most reluctant to have Indians in the top echelon of any activity. The educational pattern followed a plan towards this end in view. Study of liberal arts, languages, mathematics, etc. were allowed while technical subjects like the sciences, engineering, etc. were not encouraged. Even in this atmosphere, there were a few bright Indians who realized the importance of science and scientific investigations, and it is their zeal. European literature on science, industry, and technology; chemicals; and various forms of research equipment slowly found their way into the country. At the time of our independence in 1947, there were about twenty universities in all, most of them being teaching and examining institutions by that time. One may summarize the situation till 1947 as a state of almost zero growth. Science and technology known at that time in the country was all borrowed rather to cater for the necessities of the empire than to fulfill the desires and demands of our people. Thus in the post independent era the new government initiate process of nation building through the establishment of various institute of science and technology. Within a short period India became a self reliant nation in term of nuclear energy, space technology and other sphere of R & D in science and technology. This chapter will throw light on the growth of some sciences in India in post independent era.

3.3.2. Council of Scientific and Industrial Relation (CSIR)

The Council of Scientific and Industrial Research (CSIR) is the name of the nation-wide research platform consisting of a network of laboratories which spans the geographical dimensions of India. Its programmes which bridge various disciplines, address specific needs which arose in the process of social transformation in the post-colonial context and demands which our society faces in this period of globalization. This multidisciplinary council runs 39 laboratories and 80 field centres across the nations to carry out fundamental and applied R&D in all areas of science and technology, barring atomic energy. The dynamic dimension of the network is the pool of knowledge and expertise of over 5000 active scientists of repute, supported by over 10,000 scientific and technical personnel. This scientific infrastructure was built up over six decades at a cost of equivalent to 1 billion US dollars at current value.

3.3.2.1. Brief History of CSIR

The Council of Scientific & Industrial Research (CSIR) was founded on 26 September 1942, by a resolution of the then Central Legislative Assembly. It is funded mainly by the India Ministry of Science and Technology and it is one of the world’s largest publicly funded (R&D) organizations, having linkages to academia, other R&D organizations and industry. Although CSIR is mainly funded by Science and Technology Ministry, it operates as an autonomous body registered under the Registration of Societies Act of 1860. Dr. Shanti Swarup Bhatnagar (1894-1955), one of the brightest luminaries of Science in India, was the first Director of the Council of Scientific & Industrial Research. His untiring efforts, devotion of duty and pioneering work in the field of Chemical Sciences brought him many laurels at the national and international levels. Dr. Bhatnagar emphasized on the utilization of Science for national development and contributed greatly for the building of CSIR.

The CSIR was established in 1942 as a autonomous, non-profit organization with a wide ranging charter of functions. These included promotion, guidance and co-ordination of scientific and industrial research, collection and dissemination of information on research and industry, founding of laboratories to carry forward scientific and industrial research and utilization of the new knowledge so generated for development of industry. CSIR was also charged with other tasks such as rendering assistance to other institutions conducting research, awarding of fellowships and publishing of scientific journals.

As a springboard for scientific and technological activity, CSIR helped usher India into a scientific milieu, creating and nurturing talent in science, innovation and technology. It spawned many organizations, many disciplines and most importantly has served as a nursery and training ground for India's talented scientists and technologists.

On one hand, CSIR has assisted industry in the development of viable and globally competitive technologies and on the other, has provided backup support in exploration and exploitation of indigenous raw materials and natural resources for import substitution, pollution control and effluent treatment, waste utilization and energy conservation. CSIR's inherent strength lies in its ability to form special interdisciplinary, inter-laboratory, international groups to tackle specific research and development problems.

3.2.2.2. A Proud Record

CSIR has several radical scientific achievements to its credit. On the technology front, CSIR performance is equally impressive. CSIR announced an intellectual Property Policy in 1995 and has gone on to file annually around 500 patents in India and around 650 patents abroad, the numbers being higher than those of any single Indian organization. Over the years it has developed more than 3,000 technologies and licensed 1,500 of them to about 6,000 clients. The annual industrial production based on CSIR techniques and technologies is estimated over $1 billion. Its S&T services and inputs annually generate productivity savings of around $500 million.

CSIR was the first to introduce buffalo milk for baby food (brand name 'Amul'); it launched the wholly indigenous tractor Swaraj; developed a cost effective process for drugs for mass use; it initiated the design of building foundations suitable for black cotton soil; it was the first to extract poly metallic nodules from the Indian ocean bed, based on which India became the first country in the world to be granted 'Pioneer Status', under the UN treaty on the Law of Seas; it built an all composite small aircraft, Hansa. Significant S&T activities and achievements are spread across a wide range of areas.

Aerospace S&T: The National Aerospace Laboratories (NAL), Bangalore, of the CSIR is a major player in India's aerospace programmes. It has developed world class capacity for design, development and fabrication of large components of advanced composites for civilian and combat aircraft, structural testing and analysis, aerospace electronics and systems, innovative capabilities in surface engineering etc. The activities are focussed on design, development, fabrication and airworthiness testing of small civilian aircraft and on creating, maintaining and providing high class expertise and world class test and certification facilities, such as National Trisonic Acoustic Facilities, Aerodynamics Test Facilities, Full-scale Fatigue Test facility, FRP and composites pilot plant facility. NAL is now spearheading the initiative to create a civilian aircraft industry in the country. It has already developed, designed, fabricated a two-seater trainer aircraft, Hansa-3, which has been certified for day and night flying. It is now engaged in the design, fabrication and airworthiness testing of a 9 to14 seater multipurpose light transport aircraft.

Biology and Biotechnology: CSIR's contributions in this area have been wide ranging including genomics, control of gene expressions, recombinant DNA products, to molecular and cellular biology, tissue culture, agro-biotechnology and fermentation. It had the distinction of placing India among the first few nations to develop its own multi-locus, BKM derived probe for DNA fingerprinting. Pioneering work has also been done on leishmania, cholera, cataract formation in the eye, apoptosis, and antibacterial properties of plant material. It has also developed several PCR based markers and diagnostic systems. The development of elite genotypes of Mentha arvensis has enabled India to contribute menthamenthol to the world as the leading producer of this product, along with the development of many novel and improved strains for several medicinal, aromatic and flowering plants.

Chemical sciences and technology: The area of chemical science and technology is the one in which CSIR's work has enjoyed high visibility, consequently bringing along credibility with the chemical industry, in areas of agrochemicals, drugs and pharmaceuticals, petroleum and petrochemicals, catalysts, and chemical intermediates, subsectors that call for a high level of innovativeness. Over 30 new and cost effective agrochemical processes have been developed for the production of a whole range of pesticides. Later, the focus was turned on the development of bio-pesticides. In the area of drugs and pharmaceuticals, the country felt the need for cost-effective and commercially viable technologies for a wide range of essential drugs. The development, consequently, of such drugs as for example anticancer, anti-virals, anti-bacterials, anti-glaucoma, anti-inflammatory, analgesics, and cardio-vascular drugs among others, gave the much needed fillip to a nascent Indian drug industry to emerge as the largest producer of generic drugs in the world. India is among the top five countries that possess world class capabilities for development and manufacture of new catalyst formulations. Efforts in this science based sector have yielded fruits and India now exports catalysts to the world including the western markets.

In the area of petroleum processing, a near cartel situation on technology has been prevailing worldwide. CSIR, in association with its partners, has helped to break the stranglehold, having successfully developed processes that are now commercially adopted by several Indian refineries and grass-root plants. Significant contributions in the chemical sector have also been made in the area of chemical intermediates.

Coal: In the early years CSIR helped in the setting up of all the coal washeries in the country and defined the washability index of coals for the first time. Since then, work has continued on developing new approaches to coal fines beneficiation and recovery from the washeries, design of mini-flotation plants etc. It has helped the steel industry to decide on coke blends; the power industry to evolve washing strategies and, most importantly, it has enabled the myriad small and medium sized beehive coke units in the coal belt of India to produce coke efficiently, with minimum pollution from inferior coals. There have been a pioneering endeavours in the developmental process in coal gasification and conversion of coal to liquid fuels.

Electronics: The electronics industry in the country has benefited largely from professionally developed specialized products. These include electronic systems for excitation control for the sugar and paper industries, diesel electric locomotives, AC drives for mining locomotives and a host of special purpose analytical and field instruments. CSIR is the repository of high-tech knowledge in microwave and travelling wave tubes and in klystrons and magnetrons. The capabilities in semiconductors created in its labs have provided tailor-make hybrid microcircuits for the Indian space programme and for other applications.

Food: In the area of food and food processing, several novel cost-effective and easy-to-operate techniques and processes have been developed by its laboratories in India. These cover the storage, conservation and processing of food grains, as also technologies for low-cost nutritious foods, food reservation, 'convenience foods' and nonconventional foods. S&T inputs have also gone into spices and spice products, grain-based foods of both the convenience and the specialty kinds, into the preservation, packaging and transportation of fruits and vegetables. Attention has been paid to develop appropriate and improved designs for machinery, such as those for milling for grains and pulses and other for food-packaging.

Housing and Construction*:* Modern techniques and technologies have been carefully developed to cover the whole gamut of construction activities, right from laying of foundations to fashioning of required construction equipment. CSIR designs for foundation for piles-under-reamed, bored, compaction, skirted, spliced are variously aimed to enable sound construction on varying types of soils encountered in the country. Newer and innovative building components developed have greatly helped the building industry to standardize optimal structural elements. Alternative materials which have come out of sustained R&D work utilize waste, economise on energy and are eco-friendly. In the area of structural engineering, CSIR laboratories have specialized in making design and analysis of special and complex structures such as high rise, long span, suspended, offshore structures and of ships, and in the integrity assessment of these structures. The roads sector has also benefited from designs and constructions techniques, especially those honed for using local skills and materials.

Leather: The Central Leather Research Institute (CLRI) of CSIR is the largest leather institute in the world. Its S&T inputs and extension activities have been actively transforming the traditional leather industry into a modern, vibrant and environmentally responsive one. Pioneering contributions have been made at every stage of the industry's activity starting from techniques for the flaying of dead animals and the storage of skins, using either no salt or very minimum, going on to appropriate timesaving and low-pollution tanning and processing techniques using 'low chrome' and 'no chrome' tanning chemicals, to modernization of the net operations in tanning through computer application and subsequently proceeding to develop new techniques for generating value added speciality leathers, computer-aided designs for footwear, garments, and goods, fashion colour forecasting, export certification and, not the least of all, in creating both the human resources as well as the R&D that the leather industry and the sector needs. A pioneering Leather Technology Mission has been mounted for the sustainable development of the Indian leather industry which aims at vast grass-roots coverage.

Materials: From time to time, demand for special materials has arisen from sectors like aerospace, defence or sophisticated industries for developing such materials. Aerospace materials such as high-density carbon-carbon composites, Nalar a Kevlar equivalent high strength fiber, aluminum lithium alloys, high purity aluminum. Industrial materials for special performance such as silicon carbide, silicon nitride bonded silicon carbide, silicon carbide whiskers, aluminum metal matrix and aluminum-graphite composites, special glasses for optical fibers, infrared range finders, laser glasses, radiation shielding glasses and sol-gel techniques for glass coatings etc.

Superconducting materials, Metals and Metallurgy: In the metals and metallurgy sector, technologies developed by CSIR have been utilized to establish the first plants in India for magnesium, chromium, carbon free ferro-alloys, ferro-vanadium, zirconium and titanium powders and titanium electrodes. Besides it has developed novel processes for the direct reduction of iron ore to sponge iron for mini steel plants, and the technology for the processing of polymetallic sea nodules for recovery of valuable metals; gas fired cupola for use in cast iron foundries and high grade synthetic rutile.

Minerals: CSIR has contributed in a large measure for exploitation of low grade and inferior ores by devising flow sheets for copper concentrators, manganese pan sintering, iron ore washing and sintering, low grade fluorspar and graphite beneficiation, recovery of molybdenum, nickel and copper, beneficiation of low grade chromite ores, graphite etc.

Mining: CSIR has made significant contributions to all aspects of mining operations, especially in coal mines. Studies and efforts on subsidence prediction and control have enabled the extraction of coal locked up in pillars and underneath surface structures and water bodies. CSIR has been the principal agent for designing appropriate mine ventilation systems and is now the main resource for mine disaster management in the country. It is responsible for testing and certifying the safety equipment for miners' personal and flame proof quality of electrical equipment etc. Ecology and Environment: When S&T inputs are needed to evolve national policies and to ameliorate environmental problems, CSIR is a major contributor.

3.2.2.3. Scientific Publications:

CSIR publishes 15 primary scholarly science journals- the latest introduction being Indian Journal of Intellectual Property Rights and Journal of Traditional Knowledge. It brings out 10 bulletins on specific science area such as electro-chemistry, fuel science & technology, mining research, mechanical engineering, medicinal and aromatic plant sciences etc.

3.2.2.4. International Collaboration

CSIR fosters symbiotic S&T cooperation with its counterparts abroad through bilateral and multilateral co-operation and exchange programmes. It has S&T collaborative agreements/arrangements with 30 agencies in 27 countries. It has also been participating fully in the activities of the Commonwealth Science Council, the Association for Science Cooperation in Asia, the South Asia Association for Regional Cooperation, the World Association of Industrial and Technological Research Organizations, the Canadian International Development Research Centre, and the Third World Academy of Sciences (TWAS). With TWAS it operates fellowships, both for post-Doctoral Research and for post-Graduate studies, in CSIR laboratories.

3.2.3. Defense Research Development Organization (DRDO)

The government of Independent India setup the Defence Science Organization in 1948 to advise and assist the Defence Services on scientific problems and to undertake research in areas related to defence. The Defence Research & Development Organization (DRDO) was set up in 1958, by merging the units of Defence Science Organization with the then existing Technical Development Establishments of the three Services. Subsequently, a separate Department of Defence R&D was formed in 1980, to improve administrative efficiency.

The mission of the Department is to attain technological self-reliance in defence systems and weapons. To accomplish this, the Department has the mandate to design, develop and lead on to production of the state-of-the-art weapon systems, platforms, sensors and allied equipment to meet the requirements of the Armed Forces and to provide support in areas of military sciences to improve combat effectiveness of the troops.

The Department of Defence R&D executes various R&D programmes and projects through a network of 49 laboratories of the DRDO located all over India and a Centre for Military Airworthiness and Certification (CEMILAC). It also administers the Aeronautical Development Agency (ADA), a society funded by the Department, which is engaged in design and development of the Light Combat Aircraft (LCA). These laboratories and establishments execute programmes and projects in diverse fields of aeronautics, armaments, missiles, combat vehicles, electronics and instrumentation, advanced computing and networking, engineering systems, agriculture and life sciences, advanced materials and composites and Naval R&D. They also conduct specialized training programmes in these areas. The programmes are carried out by a workforce of about 30,000 including more than 6,000 scientists and engineers, supported by a budget of the order of Rs. 30,000 million.

To fulfill its objectives DRDO has a strong partnership with about 40 academic institutions, 15 national S&T agencies, 50 PSUs and 250 private sector enterprises. This has enabled the organization to minimize the effects of sanctions and technology denials, imposed by technologically advanced countries from time to time.

During its first decade, between 1948 and 1957, DRDO was mainly engaged in activities related to clothing, ballistics, operations research, and general stores. During the next decade 1958-68, many products, including small and medium weapon systems, explosives, communication systems and cipher machines were developed. The important achievements of the next decade (1969-79), during which DRDO addressed major hardware systems included, field guns, sonar systems, radar and communication equipment and aeronautical systems. Between the years 1980-90, it embarked on programmes of a multi-disciplinary nature for the development of complex and sophisticated weapon systems having latest technology. The contribution of DRDO towards self-reliance in defence systems became evident with the development of flight simulators for Ajeet and Kiran aircraft, air launched missile target Fluffy and various other types of ammunition, low-level surveillance radar Indra, electronic warfare (EW) systems and sonars. During the decade of 1990-2000, certain major programmes undertaken during the previous decade culminated in weapons and systems, like the Ballistic Tank (MBT) Arjun, missiles Prithvi and Agni, pilotless target aircraft Lakshya; combat improved T-72 tank Ajeya, bridge layer tank on T-72; Sarvatra bridging system, artillery combat command and control system, 5.56 mm INSAS rifle; light machine gun and ammunition; the super computer PACE+, sonar systems and Naval mines. Starting out as an agency which carried out science-based technical improvements to existing systems, DRDO has grown today to a hightechnology agency capable of undertaking ab-initio design, development and integration, leading to production of world class weapon systems meeting Qualitative Requirements of the Services. DRDO has achieved technological self-reliance in ammunition, armoured systems, surface-to-surface missiles, sonar systems, Electronic Warfare (EW) systems and advanced computing.

3.2.3.1. Achievements And Programmes: Defence

Aeronautical Systems: DRDO has already delivered pilotless target aircraft Lakshya, aircraft arrester barrier, a variety of brake parachutes and balloon barrage system to the Armed Forces. The Light Combat Aircraft (LCA) programme, under execution at Aeronautical Development Agency (ADA), has led to the development of several state-of-the-art aeronautical technologies and the creation of a necessary infrastructure, despite the constraint of sanctions imposed by the advanced countries and the country's industrial base unprepared for the requisite components and advanced materials. The first LCA Technology Demonstrator (TDI) has undergone a number of successful test flights. The remotely piloted vehicle Nishant, is at an advanced stage of evaluation. Certain crucial elements, of the modernized avionics of Su-30 MKI aircraft being acquired by the IAF, have been supplied and successfully integrated.

Armaments: DRDO has achieved a high degree of developmental self-reliance in the area of armament and ammunition. More than 300 ammunition items based upon DRDO technology worth Rs. 50,000 million have been manufactured by ordnance factories. These include 5.56 mm calibre rifle and machine gun, anti-tank ammunition, illuminating ammunition, mines and a variety of bombs for the Air Force. The project for the development of a multi-barrel rocket system is at an advanced stage of evaluation.

***Missile Systems**:* DRDO has established core competence in the area of surface-to-surface missiles, which has been demonstrated through development of Prithvi missile and its variants, demonstration of reentry and related technologies for Agni-I and development of the longer range version, Agni-II. The surface-to-air missiles Trishul and Akash and anti-tank missile Nag are at an advanced stage of flight evaluation. For the first time in the world, the indigenously developed capability to hit a target at 4.18 km in top attack and the fire-and-forget mode has been demonstrated through a flight test of Nag missile.

Radar and Communication Systems: In spite of the non-availability of indigenous microelectronic devices and components, DRDO laboratories have successfully developed and delivered a variety of systems falling under this group including INDRA PC radar, equipment for Army Radio Engineered Network (AREN), very low frequency receivers, satellite communication terminals and secure telephones. A number of projects, for development of other radar and communication systems, are being carried forward.

***Electronic Warfare (EW) Systems**:* DRDO developed a number of EW systems with considerable success. These include Ajanta, Coin, Vikram and Radar Warning Receiver (RWR) for MiG-23 and MiG-27 aircraft, which have been delivered to the Services. In addition, the self

protection jammer for MiG-27, is ready for delivery. Development of an advanced RWR for MiG-21 aircraft has been completed. The current EW projects, Samyukta and Sangraha for the Army and the Navy are at an advanced stage and should reach the Services in the next few years. India is now capable of developing any type of state-of-the-art EW system for the Services.

Combat Engineering Systems: DRDO's efforts have led to successful development of a variety of complex multi-disciplinary systems including bridge layer tanks, mat fording vehicles, mine field marking equipment, mortar carrier vehicles, armoured engineering recce vehicle, armoured amphibious dozer, operation theatre complex on wheels, ward container and mobile water purification systems. The R&D expertise in DRDO and the production infrastructure in the country can now be brought together for world class engineering systems for Defence Services.

Main Battle Tank: Arjun, and its derivative systems have met stringent requirements of the Army successfully. This tank is contemporary to world class tanks like M1A2 of the USA and Leopard 2 of Germany. The bulk production of MBT Arjun is now at an advanced stage. Based on the experience gained during the development of MBT Arjun, DRDO has successfully integrated a 155 mm SP turret on Arjun derivative chassis for development of a 155 mm self-propelled weapon system. It has also modernized the T-72 M1 tank to improve its fire power, mobility and protection.

Underwater Warfare Systems: This has been another area in which a solid foundation for selfreliance has been established by successful development and delivery of a number of sonar systems, including Simhika, Humsa, Humvad and Panchendriya and a number of Naval systems including triple tube torpedo launcher and Processor Based Ground Mine and Processor Based Moored Mine. The systems in advanced stages of development include Mihir and Nagan sonars, advanced experimental torpedo Shyena and also wire guided torpedo.

3.2.3.2. Other Major Achievements: Civil

Advanced Computing and Software Products*:* DRDO has successfully developed Supercomputer PACE+, consequent to the denial of such a computer by the advanced countries. DRDO's expertise in software has been demonstrated through the development and commissioning of war games Shatranj and Sangram for the Army; Sagar for the Navy and air war game software for the Air Force. A landmark toward self-reliance in microprocessor technology has been achieved through development of ANUCO, a floating-point coprocessor and a 32-bit RISC processor ANUPAMA. Its processing speed is being further enhanced from 33 MHz to 350 MHz. In addition, a three-dimensional medical imaging system 'ANAMICA' has been developed. Softwares called GITA (Graphical Interactive Three Dimensional Applications, a general purpose CAD software and AUTOLAY, a design for software manufacture is being marketed internationally. DRDO has also set up a Very Large Scale Integrated Circuits (VLSI) design facility, which has been used for developing a number of Application Specific Integrated Circuits (ASICs) like the digital signal processing chip.

Critical Electronic Components*:* Initiatives to achieve self-reliance in the field of electronic components has been taken by setting up facilities for production of Gallium Arsenide and Silicon devices. Under the programme, CODE, several types of components have been indigenized, like integration components, microwave components, millimeter wave components and other special types of components required for various ongoing DRDO programmes.

A facility has been created to lead to fabrication of Gallium Arsenide wafers and Monolithic Microwave Integrated Circuits (MMICs) in 1-18 GHz range. Under a co-operative venture with other S&T Departments and Industry, DRDO has contributed in setting up a silicon foundry which has the potential of making the country independent of foreign sources in respect of most of the VLSI requirements.

Electronic and Strategic Materials*:* DRDO has developed several types of strategic materials like 'Jackal M-1' steel for bullet-proof jackets and bulletproof vehicles; aluminium alloy for structural applications in the Light Combat Aircraft; single crystal super alloy and directionally solidified super alloy for use in high performance aero-engines; fibre reinforced plastic (FRP) composites for immunity against small arms ammunition and missile fragments on board ships; kevlar/aramid composite material for light weight combat helmet and rare earth based high energy magnets for application in India's space programme. DRDO has undertaken certain initiatives for making the country self-sufficient in a number of strategic materials, like setting up a facility for carbon fibre and prepegs for application in aerospace structures; launching of a national programme for development of smart materials and technology development for high purity alumina substrate and PTFE soft substrate for use in microwave integrated circuits. Technology for Fullerenes and carbon nano tubes which have potential applications in stealth, smart materials and micro-electronics have been indigenized and facilities for nano tubes at 5 gm/day level has been established. Metal/Material Processing Technologies: The technology to convert titanium tetrachloride into titanium sponge, which is a closely guarded secret of the few titanium sponge producers in the world, has been developed which will enable India to utilize the world's largest reserves of titanium which the country has. This can be gainfully utilized in defence, aerospace, oil and power sector industries. In addition, innovative processes comprising air induction melting and electro-slag refining have been developed to produce iron aluminide based advanced inter-metallics. Aluminium based particulate metal matrix structural composites for aerospace applications have also been developed.

Technologies and processes such as ion plasma deposition of protective layers and laser processing have been established. Two grades of ultra clean structural and armour steels of High Strength Low Alloy (HSLA) steel variety, copper-boron and armour, have been designed and developed for structural and armour applications in marine vessels.

Radar and Communication Technologies*:* To meet the requirements of modern radars, namely longer detection ranges, faster data rates (short reaction times) and ability to accommodate increased target densities, DRDO has indigenously developed the technology area of array design and developed expertise in the development of radiating elements, taking into account the mutual coupling, collimation and beam steering, feeds etc. A planar, phased array system has been successfully implemented in Rajendra radar. Another achievement is the speech secrecy systems based on state-of-art encryption techniques for telephone secrecy (speech), secrecy over radio and multi-channel (bulk) secrecy over voice and data. The satellite communication terminals, based on state-of art techniques like spread spectrum multiple access, high grade secrecy and low bit-rate voice digitization, have been developed. One such terminal in S-band was used during the Orissa cyclone in 2000, for communication with remote villages.

Missile Technologies*:* During the execution of IGMDP programme, DRDO developed several technologies that have gone into various missile systems. These include: strapdown inertial guidance system, high strength low weight magnesium alloy wings; manoeuvrable trajectory; accurately deliverable high lethality field interchangeable warheads; multiple target tracking; composite airframe; nitramine based smokeless propellant; ram rocket technology; three beam command guidance system; carbon-carbon technology; and maneuverable re-entry guidance and control for long range missions.

Naval Technologies*:* During the course of the development of indigenous surface, ship and submarine sonars and other sonar systems by DRDO, a number of technologies have been developed. These include multi-channel sonar signal conditioning and data acquisition; sonar signal processing hardware; sonar display systems; sonar simulation and sonar power amplifiers. In the development of underwater acoustic transducers of various types, special acoustic materials like polymers, polymer matrix composites, elastomers and adhesives have been developed along with expertise in engineering aspects like packaging underwater sealings and encapsulations. DRDO is a world leader in development of Impressed Current Cathodic Protection (ICCP) technology to supplement the protection provided by paints to underwater structures against sea water corrosion. Work is in progress on 'Dual Zone' ICCP system. Fire retardant intumescent paint; non skid and high performance exterior paints and polymer based materials like vibration damping material; ion exchange-cum-indicator resin and polyurethane sealant have been developed. Work is also in progress on fuel cells as an alternative source of power. In the area of underwater weapon propulsion, magnesium-silver battery technology and contra rotating motor with indigenous design and technology have also been developed. Machinery Control Room (MCR) simulators for training engine room crew have been developed. The DRDO-developed hydrophone system was used to detect Gujarat earthquake victims buried under the debris, based on which it was possible to rescue five persons.

Agriculture and Life Science Technologies*:* Cold desert agro-animal technologies have helped to sustain the population of Leh (Ladakh) and to meet the requirements of military and para-military forces deployed in these regions. These technologies have helped to grow off-season vegetables for soldiers and the local people. Growing of fresh vegetables locally and greenhouse cultivation during frigid winters are saving considerable transportation costs for the Army.

DRDO has helped in establishing a self-sustaining village, Nang, at a height of about 4,000 m. It has developed technology for soil-less agriculture or 'hydroponics' which is very effective in areas not having suitable soil and where economy in water use is mandatory. An internationally acclaimed concept of 'radio iodine split dose therapy' for management of hyperthyroidism has been developed. In addition, several man-machine and man-medicine interface technologies and food preservation and food processing technologies have been developed.

3.2.3.3. National Infrastructure Assets

DRDO has been instrumental in creation of sophisticated and high cost R&D facilities for test, evaluation and other purposes. These may be termed assets, as these fulfill the requirements not only of DRDO but also of other scientific organizations and of the industry. A brief account of such facilities created, is presented.

Range Test Facilities: To meet the requirements of various missiles and other weapon system development programmes, a total of four launch complexes have been established: three at Interim Test Range, Balasore, and one on an island. These launch complexes suit specific requirements without affecting the natural environment in the test range. The range of instrumentation includes sophisticated radars, electro-optic tracking system, telemetry system, range computer and wide band data acquisition and processing system. With the help of these sophisticated instrumentation, the post-flight data are available within thirty minutes of the flight.

In the recent past, the range facility was utilized by Ministry of Defence, Singapore, on a paid basis.

Flight Simulation Facilities: DRDO has created several flight simulation facilities to support design investigations of fighter aircraft performance, handling qualities and capabilities in close combat and mission system performance. Some of the facilities include: research flight simulation facility, pilot-in-loop flight simulation facility, air combat simulator, mission avionics systems simulator, cockpit environment facility and aircraft system maintenance simulator. A virtual reality centre has been set up to address the requirements of virtual prototyping of LCA. The Aeronautical Material Testing Laboratory (AMTL), a national facility, is one of its kind for testing aeronautical material and components. In addition, under Aeronautics Research & Development Board (AR&DB), DRDO helped in setting up of sophisticated test facilities at IISc, Bangalore, IITs, some universities and at other technological institutions like NAL, to support R&D in aeronautics and applied science.

Some of these major facilities are: modified trisonic wind tunnel (NAL), 200 mm hypersonic wind tunnel (IISc), high temperature low cycle fatigue test facility (IIT-B) and full-scale fatigue test facility (NAL).

National Centre for Automative Testing: DRDO has set up a National Centre for Automative Testing (NCAT), at Ahmednagar, for testing and evaluation of automotive vehicles, their systems and components for certification for compliance of various national/international standards. Spread over an area of 450 acres, this facility consists of track testing and testing for emission, photometry, EMI and safety and has necessary supporting infrastructure to provide a one-stop solution to the requirements of Indian automotive industry. A variety of test tracks and facilities are spread over an area of 450 acres. The test tracks simulate a variety of ground/road surface conditions which a vehicle normally encounters during its span of use.

Electronic Warfare Test and Evaluation Facilities: DRDO has created Electronic Systems Evaluation Centre (ELSEC) for ground integration of EW systems and testing of systems under real life conditions. A Range on Wheels (ROW), comprising six mobile ground stations has been made operational. It is a unique facility for evaluation of airborne EW systems during development, user acceptance and system enhancement phases. The setting up of EW Simulation Testing and Evaluation Station (SITES) and Microwave Components Qualification and Testing Centre (MQTC) is in progress.

Underwater Research Facilities: A premier research facility called High Speed Towing Tank (HSTT) for carrying out studies on experimental hydrodynamics related to model testing of ships, propellers and submerged bodies has been set up. An Underwater Acoustic Research Facility (AURF), a lake facility established by DRDO at Kulamavu in Idukki district of Kerala, carries out calibration and full-scale testing of underwater acoustic transducers, array and other sub-sea equipment like fish finding sonars, echo sounders and underwater communication systems. A dedicated research ship Sagardhwani equipped with state-of-the-art laboratories has been developed and is being used for collection of oceanographic data. Materials and Transducers Simulated Test facility (MATS), the only one of its kind in the Asia Pacific region and one of the very few in the world, has been established recently which provides static and dynamic measurements on materials and transducers under different conditions of temperature and pressure, simulating ocean depths. The setting up of an underwater range and a cavitation tunnel facility is in progress.

3.2.3.4. R&D For Societal Benefits

Besides R&D in defence sector with a lot of innovation for the security of the nation, DRDO is also working hard for the benefit of the general public. Since its inception DRDO has innovated a long range of product for the benefit of general mass. Some of the product are as follow

Floor Reaction Orthosis (FRO): As a medical spinoff of advanced composite technology used in making missile nose cones, Floor Reaction Orthosis, a walking aid for polio patients with quadriceps muscle weakness, has been developed. This weighs only 300 gm, as against 3 to 3.2 kg for the commonly used variety, is inexpensive and can be worn easily with and without shoes. More than 2,500 such walking aids have been fitted to polio handicapped persons in camps organized for this purpose.

Coronary Stents: Using special grade austenitic stainless steel, developed for LCA and missile programmes, two types of stents have been developed for dilating constricted arteries. Over 115 stents have been fitted in patients so far. The cost of the indigenous stent is Rs. 15,000 as against Rs. 40,000 or more for the imported one.

Cardiac Pacemaker*:* An external pacemaker hasbeen designed and developed for intensive care of patients suffering from degenerative heart diseases. The system has been clinically validated at Nizam Institute of Medical Sciences, Hyderabad. Efforts are being made to convert it into a portable system.

Cardiovascular Catheters*:* These have been developed to offer a heart patient the option of nonsurgical treatment of defect within the heart and the rest of the circulatory system. The cost of the indigenous catheter would be Rs. 1,500 against Rs. 4,500 for the imported one.

Cardiac Stress Test System*:* A PC-based, low cost indigenous system has been developed to acquire and analyse the ECG of a person doing exercise. The system comprises a standard protocol of graded exercise programme, acquisition, analysis and documentation of ECG and trends in BP, heart rate and ECG, indicating heart abnormalities. The system hardware consists of a 12-channel ECG data acquisition system and is priced at Rs. 350,000 to 400,000 as against Rs. 1.2 to 1.5 million for the imported one. The system is in operation at Air Force Hospital, Delhi, and its technology has been transferred to trade.

Cytoscan*:* Using the latest pattern recognition and image processing technologies, a computer aided cancer detection device has been developed by DRDO. The system is used for diagnosis and prognosis of several cancers, including cervical and breast cancer. The system has been used for detection of cervical cancer amongst tribal women in Andhra Pradesh under Project Tulsi, funded by the Ministry of Social Welfare. The programme will be extended to rural areas of Bihar, Madhya Pradesh, Rajasthan and Uttar Pradesh. More than 20,000 rural women have been scanned so far.

Dental Implants*:* Using commercially pure titanium, a technology has been developed to design and fabricate titanium endosteel implants and bone plates. It has tremendous application in oral and skeletal rehabilitation. The Drug Controller of India, Ministry of Health & Family Welfare, has accorded approval for multi-centric clinical trials.

Water Desalination Technology*:* DRDO has developed water desalination, testing and purification technologies, based on which 30 desalination plants have been commissioned in 25 villages of Barmer district of Rajasthan under PhaseI of project Sujalam. A water testing field kit has been developed in accordance with the requirements of National Drinking Water Mission, for quick assessment of chemical and bacteriological quality of water for potability. The technology has been transferred to industry.

Tissue Bank Facility: A tissue bank facility has been created by DRDO for preparation of radiation processed chorioamnion grafts. The grafts are extremely useful for treatment of burn injuries. The facility can provide 2,000 grafts per year.

Avalanche Forecasting: The organization has set up a number of observatories and automatic weather stations at various locations, based on which, avalanche forecast warnings with high accuracy are being issued to areas of Jammu and Kashmir, Himachal Pradesh and Uttar Pradesh. An 'avalanche victim detector' has also been developed to locate avalanche victims and facilitate rescue operations.

Jammer for RCIED: The Remote Control Improvised Explosive Devices (RCIEDs) are being used by criminal and anti-national elements by integrating devices, such as, cordless telephones, remote bell, remote control toys, garbage door openers and DTMF transceivers with explosive devices. DRDO has successfully developed a system as a counter-measure against RCIEDs. This system prevents the command signals entering the RCIED, which is initiated by a handheld transmitter. The system can be installed on an Ambassador car for VVIP security, on Armada Jeep or a Tata Sumo vehicle, for paramilitary convoy protection.

Bio-digesters*:* A consortium of bacteria and digesters for disposal of human waste through microbial degradation in an eco-friendly manner, for use in high altitude, low temperature areas has been developed. Some of these, installed at high altitudes and glacier regions, are functioning satisfactorily.

Explosive Detection Kit: DRDO has developed a kit for detection and identification of explosives. It can detect and identify explosives based on any combination of nitroesters, nitramines, trinitrotoluene (TNT), dynamite or black powder. The testing requires only 3 to 5 mg of suspected sample and only 3 or 4 drops of reagents.

Long-Term Storage of Tender Coconut Water*:* A technology has been developed to preserve tender coconut water, a delicious natural and healthy drink rich in minerals, especially potassium. The drink is stored in aluminium cans and flexible polymeric pouches to preserve its natural characteristics up to six months. The technology has been transferred and the product is now being marketed.

3.2.3.5. Interaction with Academia

DRDO has constituted four research boards to nurture and harness talent in academic intuitions, universities, R&D centres and industry. The organization provides necessary facilities for promoting basic research and to catalyse cross-fertilization of ideas with R&D agencies in other sectors for expanding and enriching the knowledge base in their respective areas. The boards provide grants-in-aid for collaborative defence-related futuristic frontline research having application in the new worldclass systems to be developed by DRDO.

3.2.3.6. Collaboration with Industry

Eight DRDO laboratories working in the area of advanced materials, robotics and artificial intelligence, communication systems, life-support systems, corrosion protection, advanced composites and desert technologies have been opened to the industry. Several technologies have been transferred to private industry such as the Scara robot, used for assembly jobs and the articulated robot used for material handling, welding, spray-painting etc. In a number of areas involving emerging technologies in which industries are not willing to invest setting up defence-specific manufacturing facilities, DRDO has also been collaborating with other departments as well as industry to help transform defence technologies for developing products for the civil sector. As these exercises involve long gestation periods, technological risk, lack of continuity of orders and lack of economy of scale, DRDO has assisted in setting-up dedicated facilities in such areas. Some of these initiatives are like; Heavy Alloy Penetrator Project (HAPP), Bharat Dynamic Limited (BDL), Hindustan Aeronautics Limited (HAL), Non-Ferrous Technology Development Centre (NFTDC), Advanced Research Centre International (ARCI). The contributions made by these Centre promoted the interest of Indian defence.

3.2.3.7. Training Schemes

DRDO has introduced a number of schemes for training of defence-science personnel in universities and other leading academic institutions. It also has two training institutions namely, Institute of Armament Technology (IAT) at Pune and Institute of Technology Management (ITM) at Mussoorie. These institutes provide specialized training programmes in diverse fields. Besides, a DRDO laboratory, the Defence

Research & Development Establishment at Gwalior, has been recognized as a centre for training inspectors who are to be appointed by the UN Organization for Prohibition of Chemical Weapons.

3.2.4. Space Research

Space research in India, including space science and technology, has a long tradition. The first Indian satellite has been named 'Aryabhata' after the famous mathematician-cum-astronomcr, forging the link between modern India and her glorious past when astronomy and mathematics were used to determine the orientation and configuration of the stars, and to construct platforms for lighting the flies for the well-being of the community. Since then the instruments and tools for space research have changed keeping however in mind meaningful use of such space activities. While India cannot afford to send a man on the moon, the objective of space research will continue to be the best utilization of the fruits of space research for the quickest progress and development of the nation in the priority-oriented economic and social sectors so that it can contribute not only to its own welfare and growth but also to the peace and advancement of the international community. In fact, this very attitude of India in aiming at self-sufficiency in technology with a view to playing its proper role in the world has been of great help in the development of space research.

3.2.4.1. Brief History of Space Research in Colonial India

Establishment of Observatory: An important chapter in India's space research was opened between 1780 and 1790 when the Nungambakkam observatory in Madras initiated a new phase of study in the field of climatology associated with meteorology, weather prediction, and allied subjects. This area of applied science has today developed into one of the most advanced technologies, which utilizes satellites. The Madras astronomical observatory undertook studies in the fields of astronomy, geography, and navigation in India by systematic meteorological observations beginning around 1796. In 1823 the Colaba observatory in Bombay was established for astronomical and magnetic studies. In 1835 the Survey of India in Calcutta began to contribute to the knowledge of geophysical phenomena.

The starting of the Trivandrum observatory in 1836 expanded the scope for astronomical and meteorological studies. Geomagnetic studies commenced in Simla in 1841. An additional observatory was established in 1852 on the summit of Agasthyamalai near Trivandrum at an altitude of 6,200 ft. above sea level. This observatory facilitated the study of the effect of altitude on magnetic and meteorological elements. The data thus obtained were necessary to verify theories of semidiurnal oscillation of the tropical atmosphere. The discovery in 1858 of the 27-day periodicity in the daily variation of the geomagnetic field is one of the important contributions including 'the study of lunar and lunisolar variations of temperature and of time variation of the magnetic field during magnetic storms' by Moos at Bombay during this year that is also worth mentioning.

The Agra observatory in 1862 and the Nagpur observatory in 1869 further widened the scope of studies of meteorological-cum-climatological subjects in this country. In 1875 the India Meteorological Department (IMD) assumed the responsibility of co-ordinating the meteorological studies reported from various centres. The establishment of a solar physical observatory at Kodaikanal in 1899 promoted the study of astrophysics. In the course of research at this centre it was found that fluxes of gases flew out from the regions above sun-spots. This discovery encouraged the space scientists in India, especially those dealing with astrophysics, solar-terrestrial physics including ionosphere, solar radio astronomy, solar X-rays, solar cosmic rays, and geomagnetism involving also studies on the interaction of solar radiation on the upper atmosphere.

Study of upper atmosphere: In 1902 the Survey of India undertook systematic field observations for the preparation of terrestrial magnetic charts of India. Scientific studies on the mutual interaction of radio waves and the upper atmosphere began in 1925 when the University of Calcutta founded a wireless laboratory. Atmospheric studies and observations up to 35 km. dealing particularly with the distribution of temperature and humidity made rapid strides due to the efforts of IMD. It introduced many of the latest methods for weather studies using balloons and similar instruments. For example, by 1928 a pilot balloon section was established as an adjunct to the meteorological branch of the Trivandrum observatory. The temperature, pressure, and humidity data collected at different heights were used by IMD and for the purpose of navigation etc. till these activities were suspended with the outbreak of World War II in 1939.

Cradle of space research: In 1932-33 India participated in the radio research programme of the Second International Polar Year. Ionospheric studies were started in 1933 at Bangalore and in 1934 at Allahabad where the study of astrophysics was an important field of work. Experiments on cosmic rays associated with high value of terrestrial magnetism, especially at high altitudes very close to the geomagnetic equator, were gaining momentum, leading to the establishment of an experimental unit in Bangalore in 1940 as a part of the Indian Institute of Science. This study of cosmic rays formed the nucleus of the work around which the Tata Institute of Fundamental Research (TIFR) was started in Bombay. The forties witnessed further advance in space research activities in that a radio research committee was created in 1942 for the purpose of upper atmosphere studies. Research in the field of cosmic rays also expanded at various centres in the country, especially at Bose Institute, Calcutta, and Muslim University, Aligarh. During this decade the Physical Research Laboratory (PRL) was established at Ahmedabad, which specialized in the field of cosmic rays and astronomy and took a leading role in forming 'the cradle of space research in India'.

3.2.4.2. Space Research in Independent India

Cosmic ray and radio research: Remarkable progress in the field of cosmic rays research was made during the fifties, principally at the centers located at Waltair, Varanasi, Ahmedabad, and Calcutta. Because of the tireless researches of the workers at these centres, India enjoyed a very admirable position in the field of upper atmosphere research in the world.

The radio research committee of the Council of Scientific and Industrial Research (CSIR) began publishing in 1955 a co-ordinated monthly bulletin- *Ionospheric Data*-giving statistics of six Indian stations. Eaily in 1956 the Radio Propagation Unit was formed at the National Physical Laboratory (NPL) with the scientific staff of the radio research committee secretariat. This group undertook experimental work for studies of atmospheric as well as cosmic radio noise. The research of this group also covered the activities of the scintillation of radio stars at 60 megahertz (Mhz) by installing a C-4 automatic ionospheric recorder.

The climatological-cum-meteorological studies, including cosmic ray, terrestrial magnetism, and radio research, flourished to such an extent that India proved to be an indispensable participant in the International Geophysical Year in 1957-58. In collaboration with the Smithsonian astropomical observatory, the observatory at Naini-Tal undertook in 1957 the tracking of satellites. In 1958 TIFR flew successfully the first constant altitude plastic balloon made in this country. Encouraged by this initial success, arrangements for launching balloons were made at Hyderabad, from where many more major flights have been carried out since 1959.

Cosmic ray research at low latitude in general and the geomagnetic equator in particular was facilitated by means of balloons, permitting the detection of very high energy cosmic ray particles that arc admitted into the earth's atmosphere. With the addition of suitable equipment, the Hyderabad balloon launching facility was utilized for equatorial experiments by research workers not only from India but also from the U.S.A. and U. K. Because of the significant contribution of Indian scientists in respect of the knowledge of cosmic rays, especially from the geophysics point of view, India participated in 1959 in the world-wide space research activities of the International Geophysical Congress Council.

The beginning of 1960 was marked by several features in the further expansion of the field of Indian space research. The Physics Department of the University of Delhi initiated research this year on the ionosphere which yielded useful information on the ionospheric parameters as well as internal gravity waves. The first high altitude cosmic ray experiment with the Indian balloon launched from Hyderabad was successful and was able to collect very useful data for further advancement of cosmic ray research in the world.

Peaceful use of Outer Space: In the latter half of 1961 the Government of India participated in the efforts of the international community for the exploration of outer space for peaceful purposes. This year also saw the establishment of the Real Time Satellite Telemetry station at PRL, Ahmedabad, in which the

National Aeronautics and Space Administration (NASA) of the United States collaborated. This station made possible the gathering of data for the solar X-ray flux from the different NRL satellites as well as radio beacon data from S-66 satellites. The Department of Atomic Energy (DAE) took a leading role in 1962 in the formation of the Indian National Committee for Space Research (INCOSPAR) with its headquarters at PRL, Ahmedabad. This was a landmark in India's promotion of space research for peaceful purposes and in her efforts for international co-operation in this field.

Thumba Equatorial Rocket Launching Station (TERLS): By this time rockets were already being used by advanced nations as a routine exercise for sounding the upper atmosphere. These sounding rockets, INCOSPAR thought, could also be launched in this country from the geomagnetic equator, especially where the upper atmospheric layers at the altitude between 90 and 130 km. revealed unexpectedly enormous diurnal variation of the terrestrial magnetic parameters. INCOSPAR started work towards the establishment of an equatorial sounding rocket launching facility at Thumba, Trivandrum.

As a preliminary step it was felt necessary to train up personnel in all aspects and disciplines required to support such a station through collaboration with NASA. Accordingly, an agreement was signed between DAE on behalf of the Government of India and NASA from the side of the Government of the United States. This agreement provided that Indian scientists and engineers would receive training in the areas of sounding rocket launching, including ground support, at the launching station at Wallops Island and the Goddard Space Flight Centre, U.S.A.

Since this station would serve virtually as the only international equatorial sounding rocket facility of its kind to support the United Nations' efforts for the peaceful use of outer space, experts from several leading space powers were deputed by the United Nations to help INCOSPAR in identifying the region in Trivandrum with appropriate instruments for detecting the zero magnetic dip locations. Thus a new era began in India's space research from both national and international considerations.

Launching of Sounding Rockets: In 1963 the first International Seminar on Space Physics was organized in India by PRL at Ahmedabad. PRL was also given the administrative responsibility for TERLS (Space Projects) by DAE. In the later half of 1963 the first sounding rocket programme was inaugurated at TERLS. The rockets required for the initial series of experiments for this programme were not available in the country, hence all these requirements were met by the assistance of NASA, USA, *Centre Nationale Etudes Spatiale* (*CNES*), France and the Hydro Meteorological Services of the U.S.S.R. Instruments for studying the upper atmospheric wind flow pattern by means of sodium vapour payload were launched on a two-stage sounding rocket made in France, called *Centaure,* on 21 November 1963 from TERLS.

Rocket Research and Development: In 1964 a team of scientists from UN visited TERLS in order to enlarge the scope of space research activities in India for collaboration with the world body. At about the same time, for promoting indigenous rocket manufacture and thereby ensuring the continuation of sounding rocket programmes, an agreement of collaboration was reached with *CNES,* France, for transfer of know-how to fabricate rockets in India. To develop rockets of Indian design, the Atomic Energy Commission approved the establishment of the Space Science and Technology Centre (SSTC) at Trivandrum. This Centre was entrusted with the major responsibility of developing sounding rockets of superior performance as well as generating technical skill and expertise in aerospace engineering and scientific payload construction for rockets and satellites. To supplement the achievements of space research with rocket-borne instruments ground-based experiments were necessary for which this Centre was also given responsibility. In the meantime, electro jet study over Thumba came to prominence when a magnetometer was launched on a sounding rocket in 1964.

Impressed by the success in rocket-launching operations as well as by the data already generated by rocket-borne experiments, IMD became interested in initiating a programme of rocket meteorology. Accordingly, collaborative agreements were concluded between IMD and NASA. The initial experiments also encouraged the scientists of the U.S.S.R. to collaborate with India for upper atmospheric research from TERLS, and agreements were signed between INCOSPAR and the Hydro Meteorological Services of the

U.S.S.R. for closer mutual co-operation. By the end of 1964 sixteen sounding rockets were launched from TERLS with scientific instrumentation designed for experiments up to an altitude of 180 km. under the joint collaboration of India, France, the U.S.A., and the U.S.S.R.

Experimental Satellite Communication: The year 1965 saw an interesting achievement in Indian space research and associated activities with the holding of the Second International Seminar on Space Science and Technology at Kodaikanal and TERLS under the joint auspices of UNESCO and INCOSPAR. Impressed by the series of successful launching experiments planned by the Indian scientists with international space research experts, the UN General Assembly accorded approval for UN sponsorship of TERLS.

That one of the most practical applications of space research is the utilization of satellites for telecommunication purposes came to be realized very soon. With a view to acquiring the capability and expertise in such communication INCOSPAR established at Ahmedabad an Experimental Satellite Communication Earth Station (ESCES) with aid from a special fund of the United Nations which approved the project in 1965. Meanwhile, work in other fields of space research was advancing fast. Under the programme of the International Quiet Surf Year (IQSY) India took a leading role.

Progress During 1965-75: The growth of space research activities during 1965-75 was enormous. At the end of 1965-66 TERLS had already lunched several sounding rocket launchings. At ESCES, Ahmedabad, the first International Training Course for Satellite Communication Technology was organized and T. V. link tests with Japan and Australia were successfully conducted. In the same year the first Indian rocket developed at SSTC and named *Rohini-75* was successfully launched from Thumba. An eventful era in the history of space research in India began in February 1968 when the Prime Minister dedicated TERLS as a UN-sponsored International Range. During this year India participated in the Third International Seminar on Equatorial Astronomy and Space Physics, and DAE was entrusted with the task of establishing a satellite communication ground station near Pune.

2.3.4.2. Establishment of ISRO

In 1969 INCOSPAR was reconstituted under the national body affiliated to COSPAR, viz. Indian National Science Academy (INSA), and it continued to establish links with COSPAR. Though this Committee is responsible for promoting and supporting international co-operation in space research and in the peaceful uses of outer space, the programme of space research and its utilization for peaceful purposes was entrusted to the Indian Space Research Organization (ISRO) with headquarters at Ahmedabad, created by DAE in the same year. By the middle of 1972 a separate Department of Space (DOS) and a space commission were created by the Government of India, when ISRO was brought under the new Department.

Objectives Of ISRO: The principal objectives of ISRO are: (i) application of space science and technology to further national goals in mass communication and education via satellites as well as the survey and management of natural resources through remote sensing technology from space platforms; (ii) development of space technology in India with the maximum degree of sclf-rcliance to further the aforementioned applications in the matter of design, development, and fabrication of satellites and rocket systems with their related tests and operational facilities; and (iii) utilization of the spin-offs from developments in space research in other fields of research, industry, education, and related areas. The activities of ISRO are thus aimed at harnessing developments in space science and technology for the socio-economic progress of the country. While ongoing programmes are continuously reviewed in the light of new developments in India and abroad, basic research and co-operation with other institutions in India are fostered selectively. Attempts are being made to establish links between national and international agencies as well as developing countries that may like to send teams for training courses organized by ISRO from time to time.

The activities of ISRO are carried out at its four space centres, namely, (i) Vikram Sarabhai Space Centre (VSSC) at Trivandrum, Kerala; (ii) Space Applications Centre (SAC) at Ahmedabad, Gujarat; (iii)

ISRO Satellite Centre (ISAG) at Bangalore, Karnataka; and (iv) SHAR Centre at Sriharikota, Andhra Pradesh. Given below are brief descriptions of the activities of these four centres.

***Vikram Sarabhai Space Centre*:** Vikram Sarabhai Space Centre (VSSC), named after Vikram A. Sarabhai (1919-71), founder of the Indian space programme, is the pivotal unit of ISRO. It is responsible for research and development activities in space technology and all aspects of work related to the development of sounding rockets and satellite launch vehicles, scientific and technological payloads, ground-based and vehicle-borne instrumentation, and production facilities for propellants and rocket hardware. It has been responsible for building the ground facilities for testing and launching rockets. Under these two projects, VSSC has built and launched the *Menaka* and *Rohini* (including *Centaure)* scries of sounding rockets for meteorological and scientific investigations of the upper atmosphere.

India realised quite early that sustaining the space programme in the long run would depend on indigenous technological capabilities. Keeping this in view, besides building satellites, India embarked on satellite launch vehicle development in the early 1970s. The first experimental launch vehicle SLV-3 was carried out in 1980. An augmented version of this vehicle, ASLV, was launched successfully in 1992. India has now acquired a significant capability in the launch vehicle area with the successful development of Polar Satellite Launch Vehicle (PSLV), capable of putting a 1,000-1200 kg class satellite into 820 km polar sun-synchronous orbit. PSLV is 307 being offered to launch the satellites of other countries and has launched two small satellites, one for Korea and another for Germany along with India's IRS-P4 in May 1999. More space agencies are expected to use PSLV for placing their satellites in orbit; a European satellite PROBA is scheduled for launch as a piggy back on board next PSLV.

The Geo-synchronous Satellite Launch Vehicle (GSLV-D1) had its maiden successful flight on April 18, 2001, from Sriharikota injecting the G-SAT 1 satellite into 180 x 32,155 km geosynchronous transfer orbit (GTO). The adjoining figure shows different types of sounding rockets and satellite launch vehicles developed and launched by ISRO.

Space Applications Centre (SAC) : Space Applications Centre (SAC) is engaged in the planning and execution of the space application projects of ISRO. Its objective is to apply space science and technology to practical uses. To achieve this objective SAC has taken up work in telecommunications and television broadcasting and reception via satellites; use of remote sensing techniques to survey natural and renewable earth resources; and studies in space meteorology and satellite geodesy. SAC also made progress in the areas of re mote sensing applications, meteorology, geodesy, and microwave engineering. SAC has also developed microwave systems as well as work on satellite geodesy and meteorology.

ISRO Satellite Centre* (*ISAG): ISRO's satellite centre, ISAG, at Bangalore, is responsible for designing, fabrication, and integration of spacecraft and the development of satellite technology. The first Indian satellite, *Aryabhata*, named after the famous ancient Indian astronomer and mathematician, was designed and fabricated at this centre. With the launching of *Aryabhata*, India acquired indigenous capability in satellite technology, namely, to design and fabricate a space-worthy system and evaluate its performance in orbit, evolve the methodology of conducting a series of complex operations on the satellite, and set up the necessary receiving, transmitting, and tracking systems, besides the establishment of the infrastructure for fabrication of satellite systems.

***SHAR Centre*:** The SHAR Centre at Sriharikota Island in Andhra Pradesh is being developed as a range for launching bigger satellite launch vehicles like ASLV and PSLV. As already mentioned, India's first satellite launch vehicle SLV-3 was launched from here. A comprehensive test facility for conducting various ground tests of rocket motors and sub-systems has been set up at this centre.

Among many other activities of ISRO mention may be made of its participation during 1979 in the Monsoon Experiment (MONEX), a regional component of an international study designated Global Atmospheric Research Programme. MONEX was conducted jointly by the World Meteorological Organization and the International Council of Scientific1 Unions. IMD was the main executing agency of this project in India. ISRO's contribution to the project comprised collection of wind data using rockets and meteorological data collected by using omega sondes.

3.2.4.3. Research in Space Sciences

Basic research in space sciences was conducted primarily at PRL and VSSC using various rocket and satellite-borne instruments with the object of understanding the structure and dynamics of the upper atmosphere, solar terrestrial relationships, and problems in astrophysics. A plasma-physics laboratory was set up to study the various ionospheric phenomena observed under laboratory simulated conditions. Artificial recharging of ground-water in Ahmedabad is one of the main application projects undertaken by PRL, including analysis of moon samples. Success in space research demands united efforts of many organizations. The areas of study cover a wide variety of scientific disciplines and include meteorology and neutral upper atmospheric physics with its related area of aeronomy, ionospheric physics, geomagnetism, cosmic rays, solar planetary physics, solar terrestrial interaction, astronomy based on optical radio, X-rays and gamma rays by means of ground-based as well as rocket and satellite-borne experiments, geophysics, geocosmophysics, and archaeology-hydrology.

Some of the organizations participating in this combined research endeavour are All India Radio, Delhi; Andhra University, Vishakapatnam; Banaras Hindu University; Gujarat University, Ahmedabad; Indian Institute of Astrophysics, Kodaikanal; Indian Institute of Geomagnetism, Bombay; Indian Institute of Science, Bangalore; India Meteorological Department, Pune; Institute of Radiophysics and Electronics, University of Calcutta; Kurukshetra University; National Physical Laboratory, New Delhi; Physical Research Laboratory, Ahmedabad; Punjab University, Patiala; University of Delhi; Kerala University, Trivandrum; University of Udaipur; U. P. State Observatory, Naini Tal; Vikram Sarabhai Space Centre, Trivandrum; and Tata Institute of Fundamental Research, Bombay.

3.2.4.4. Indian National Satellite (INSAT) System

A major development took place during 1980s, through the establishment of the operational Indian National Satellite (INSAT) system, for providing indigenous services in telecommunications, TV broadcasting, meteorology and disaster warning. The INSAT series, commissioned in 1983, has today become one of the largest domestic satellite systems in the world, comprising five satellites. The last satellite of the second generation INSAT-2 series, INSAT-2E, was launched from Kourou, French Guyana, on April 3, 1999. Work on INSAT-3 series of satellites has already begun. Five satellites in the INSAT-3 series have been planned and the first satellite, INSAT-3B, has already been launched in March 2000. The INSAT system has a unique design, combining telecommunication, television/radio broadcasting and meteorological services upon a single platform. The involvement of various users like the Department of Telecommunication, Ministry of Information and Broadcasting, Indian Meteorological Department, has enabled proper tuning of INSAT system towards identified national developmental needs.

The demonstrated space applications in SITE and STEP of the 1970 were transformed to practical and operational systems through INSAT. Today, INSAT links about 450 earth stations set up in the country, including those located in inaccessible regions and offshore islands. Besides, there are about 8,500 Very Small Aperture Terminals (VSATs), including those installed by the National Informatics Centre and private networks, catering to corporate houses.

Television in India now reaches about 85 per cent of its population through over 1,000 TV transmitters linked via INSAT. Educational programmes of over 100 hours are telecast every week. The INSAT system has become a powerful tool for training and developmental education and is used by various agencies to provide continuing education, conduct in-situ training for industrial employees, social welfare personnel and training of Panchayat Raj (village governance) workers. India continues to emphasize the use of INSAT for rural upliftment. A pilot project that started in November 1996, in a tribal district of Madhya Pradesh in Central India is now in progress to educate the indigenous community on various aspects of health, hygiene, family planning and women's rights. This project is being expanded to cover more villages and is expected to lead to a unique space-based system that will be dedicated to the development of rural society. Similar projects are being initiated in several other states.

Thus, the multi-dimensional aspect of space research and application is evident from the working of the Indian National Satellite System (INSAT). Established by DOS in close co-operation with the Ministries of Communication, Tourism and Civil Aviation, and Information and Broadcasting, the INSAT system is a multipurpose operational space enterprise providing meteorological and television services from a common satellite in geostationary orbit.

2.3.4.5. Conclusion

Space technology in India has already established the capacity of high quality research, design, and development in all the fields of space engineering like aeronautics, avionics, and electronics as well as in the processing and manufacture of sophisticated rockets and satellites. The expertise can be used for development and fabrication of large booster rockets to launch application satellites mainly for down-to-earth use. The space applications will further endeavour to utilize the support of space technology and sciencc for solving some traditional problems faced by this country with a vast rural population so long deprived of the benefits of a modern space age. The whole concentration of space application is on the major areas of satellite communication including SITE type satellites, remote sensing of natural resources for detection/ prediction of problems and prospects associated with fields such as agriculture, minerals mining, meteorology, and geodesy. The whole range of ISRO activities is tuned towards this goal.

2.3.5. Atomic Energy in India

India's Atomic Energy programme has been a mission oriented comprehensive programme with a long-term focus. From its inception the guiding principle of this programme has been self-reliance through the utilization of domestic mineral resources, and building up capability to face possible restrictions in international technology and the exchange of resources. The events of the last 50 years have, in fact, validated this approach.

The Department of Atomic Energy (DAE) in India is today a broad-based multidisciplinary organization incorporating basic and applied research, technology development and their translation into industrial application, as closely linked activities. As a result, India today builds its own thermal reactors and associated nuclear fuel cycle facilities and is well poised to march on to the second and third stages of its planned programme involving fast breeder and thorium utilization technologies respectively. This effort is expected to provide a significant long-term solution to India's crucial electricity needs to support its overall development.

The Indian Atomic Energy Commission was first setup in August 1948 in the Department of Scientific Research, which was created a few months earlier in June 1948. The Department of Atomic Energy (DAE) was setup on August 3, 1954 under the direct charge of the Prime Minister through a Presidential Order. Subsequently, in accordance with a Government Resolution dated March 1, 1958, the Atomic Energy Commission (AEC) was established in the Department of Atomic Energy. The Prime Minister (late Pandit Jawaharlal Nehru) also laid a copy of this Resolution on the table of the Lok Sabha on March 24, 1958.

According to the Resolution constituting the AEC, the Secretary to the Government of India in the Department of Atomic Energy is ex-officio Chairman of the Commission. The other Members of the AEC are appointed for each calendar year on the recommendation of the Chairman, AEC and after approval by the Prime Minster.

The Department of Atomic Energy (DAE) was set-up on August 3, 1954 under the direct charge of the Prime Minister through a Presidential Order. The vision of the Department of Atomic Energy (DAE) is to empower India through technology, creation of more wealth and providing better quality of life to its citizen. This is to be achieved by making India energy independent, contributing to provision of sufficient, safe and nutritious food and better health care to our people through development and deployment of nuclear and radiation technologies and their applications.

DAE is engaged in the design, construction and operation of nuclear power/research reactors and the supporting nuclear fuel cycle technologies covering exploration, mining and processing of nuclear minerals, production of heavy water, nuclear fuel fabrication, fuel reprocessing and nuclear waste management. It is also developing advanced technologies that contribute to the national prosperity. The spin-off technologies, human resource developed and technical services being rendered by the Department have been greatly helping the Indian industry. The Department is also developing better crop varieties, techniques for control/eradication of insects thus protecting the crops, radiation based post harvest technologies, radiation based techniques for diagnosis and therapy of disease particularly cancer, technologies for safe drinking water, better environment and robust industry.

Main Focus areas of work in DAE are firstly, increasing share of nuclear power through deployment of indigenous and other proven technologies, along with development of fast breeder reactors and thorium reactors with associated fuel cycle facilities. Secondly, building and operation of research reactors for production of radioisotopes and carrying out radiation technology applications in the field of medicine, agriculture and industry. In third, developing advanced technologies such as accelerators, lasers, supercomputers, advanced materials and instrumentation, and encouraging transfer of technology to industry. Finally, support to basic research in nuclear energy and related frontier areas of science, interaction with universities and academic institutions, support to research and development projects having a bearing in DAE's programmes and international co-operation in related advanced areas of research and Contribution to national security.

DAE has made the significant contributions to the national initiatives in the speher of agriculture by enhanced production of oilseeds and pulses. Besides, in education and health, Homi Bhabha National Institute (HBNI), National Initiative on Undergraduate Science (NIUS), are performing Countrywide Services in Cancer through Telemedicine. In food & nutrition security, Radiation Processing of Food & Agro Products. Desalination in water scarcity areas along the sea coast and electricity supply in near and long term ensuring long term sustainable development.

2.3.5.1. The Role of Nuclear Power

There is a well established link between per-capita electricity consumption and human development. The installed electricity generation capacity in the country is quite impressive but when looked at on a per capita basis, this is far below the world average. To meet our large electricity production needs, we have to tap all energy resources available to us. While coal-fired thermal power plants, apart from hydro, would remain the mainstay for our electricity production for quite some time, we would need to supplement them with sizeable additional resources to assure long-term energy-security as well as environmental protection. In this energy mix, nuclear power has an important role to play in the coming years. The Indian uranium reserves are modest and cannot make an overly significant contribution to electricity requirements, if this uranium is used once in a nuclear reactor and then disposed of as waste. However, with a carefully planned programme, the available uranium can be used to harness the energy contained in non-fissile thorium, of which India possesses about 30 per cent of the world's reserves.

2.3.5.2. Evolution of the Indian Nuclear Programme

Homi Jehangir Bhabha formulated this strategy nearly 40 years ago, when India possessed hardly any infrastructure to support the nascent nuclear technology. The first Prime Minister of India, Jawaharlal Nehru, helped Bhabha lay the foundations of the Indian atomic energy programme, with self-reliance as the motto. Accordingly, a large R&D establishment, named Atomic Energy Establishment, Trombay, was progressively set up. This was renamed the Bhabha Atomic Research Centre (BARC), after India tragically lost Bhabha in an air crash in 1966. It incorporates research reactors, basic facilities for nuclear research, supporting infrastructure, and trained human power in all disciplines dealing with nuclear energy.

The Indian nuclear power programme commenced in 1969 with the building of the twin reactor units of the Tarapur Atomic Power Station (TAPS), employing Boiling Water Reactors (BWRs), with American assistance. The reasons for this choice lay in favourable performance guarantees for these reactors, and the need to gain experience quickly in running nuclear power plants.

The construction of the first two Indian PHWRs, RAPS-1 and RAPS-2, was a joint venture project with Canada. In parallel, the DAE set up facilities for fabrication of fuel, zirconium alloy components, manufacture of precision reactor components, and for production of heavy water. The import content of RAPS-1 was 45 per cent and half of its first core fuel charge was imported. Commercial operation of RAPS-1 commenced in December, 1973. In the year 1974, India conducted the peaceful nuclear experiment at Pokhran. The Canadian support was summarily withdrawn while RAPS-2 was still under construction. France too, followed suit by refusing to supply fuel for the Fast Breeder Test Reactor (FBTR) which was then under construction with French cooperation. The USA expressed its inability to continue fulfilling its contractual obligations to supply fuel for TAPS. The era of technology control regimes had begun for the Indian nuclear programme.

Coping with the Pokhran-I fall- out: The abrupt withdrawal of foreign technical co-operation and supplies following the Peaceful Nuclear Explosion Experiment of 1974, could have caused a serious setback to the Indian nuclear programme. This did not happen on account of the nation's determination to face the challenges head-on with the help of the R&D infrastructure already created to develop self reliance, and the support of Indian industry. India's stakes lay not only in the continuation of the ongoing activities without external help, but also in the pursuit of the originally stipulated long-term strategies. To cut a long story short, although delays were caused in some ongoing projects, the embargoes spurred the growth of indigenous capability for developing substitutes for the denied products, technologies and knowhow. RAPS-2 started commercial operation in 1981; FBTR went critical in 1985, using indigenously made plutonium-uranium mixed carbide fuel; and India developed a plutonium-uranium mixed oxide fuel, as well as the facilities for its industrial scale production, as an alternative to the enriched uranium based fuel for TAPS. India has not looked back since, and has continued to proceed on its chosen path without depending on external help.

The present and the future: The country has successfully developed technologies for in-service inspection, maintenance and refurbishment of older plants. As India gains experience and masters various aspects of nuclear technology, the performance of its nuclear plants continues to improve. The average capacity factor of Indian plants in 1995-96 was 60 per cent and it has risen to 82.5 per cent during 2000-2001.

Two 500 MWe PHWRs, fully designed and developed in India, are under construction at Tarapur. In parallel, to further accelerate the growth of nuclear power, plans are being considered to build a few light water reactor based plants as an additionality, with foreign collaboration. The deal with the Russian Federation for setting up two 1,000 MWe units at Kundankulam is a step in this direction. Pre-project activities for setting up these units have commenced and DAE expects to start construction later this year. The two programmes of light water reactor and the indigenous self-reliant three-stage PHWRs, run as parallel programmes.

The Nuclear Power Corporation of India Limited (NPCIL) has gained considerable experience and confidence in plant life management, after many complex repair and rehabilitation jobs. Its nuclear power reactor maintenance capability is now on par with that of advanced countries. The intricate job of en masse replacement of coolant channel assemblies in the RAPS-2 reactor was successfully completed by employing indigenously developed technology well ahead of schedule and with minimum consumption of man-rem. The technology for tackling the OPRD (Over Pressure Relief Device) problem of the RAPS-1 leak was evolved and demonstrated and the repair work carried out successfully. From RAPS-2 onwards, improved coolant channel material and modified channel design have been adopted for longer life of the coolant channel.

Fast Breeder Programme: Studies with regard to the content of the FBR programme and the type of test reactor to be built were undertaken in the early 1960s. The construction of FBTR was started in 1972 and completed in 1984. Critical components of the reactor like the reactor vessel, rotating plugs, control rod drive mechanisms, sodium pumps, steam generators, remote fuel handling machines, turbo-alternator and instrumentation and control packages were manufactured in India. Foreign input constituted only 20 per cent of the total cost, and it was mainly towards knowhow and cost of raw materials.

An important achievement was the fabrication of mixed carbide fuel at BARC. This indigenously designed and developed fuel was unique, as the mixed carbide fuel core was being used as the driver for the first time anywhere in the world. The fuel burn-up now has crossed 72,000 Mwd/t. As a logical follow-up of FBTR, it was decided to build a prototype fast breeder reactor (PFBR) and the detailed design work was taken up at the Indira Gandhi Centre for Atomic Research (IGCAR). The design work has been completed and technology development for the PFBR is in progress, in collaboration with Indian industry.

2.3.5.3. Evolution of Research and Development

The profile of the R&D pogrammes being pursued in the research centres of the DAE has kept changing with the evolution of the country's total nuclear programme. To cite an instance from the experience of BARC, in the early years of the evolution of the programme involving setting up of PHWRs, in addition to R&D on reactor systems and components and process development for the fuel cycle and the heavy water plants, BARC provided support to nurture competence in various sectors such as the manufacture of complex equipment, plant construction, acceptance testing and calibration of equipment and components being manufactured for the first time by Indian industry or in-house facilities. Now, when the programme is well developed, many of these activities are being conducted by industry. On the other hand, newer activities involving R&D focused on technologies related to repair and refurbishment had to be taken up at BARC, to take care of the emerging needs of operating power reactors. Plant life management has now become a major programme which requires a lot of specific data to be generated, and this is being done at BARC. Adequate experience has been acquired in this area as well. Having reached a degree of maturity in the PHWR programme, the focus has once again shifted, and BARC is now working on new reactor systems, particularly the Advanced Heavy Water Reactor (AHWR). This reactor aims to utilize vast reserves of thorium available in India and incorporates several passive safety features which are planned to exceed current international expectations.

Indian technology in this area expects it to become a forerunner of similar systems, which may be developed here or in other countries. To verify some of the design features, thermosyphon studies have been conducted on specially built experimental facilities in BARC. Further, a low- to medium-pressure experimental facility is being set up at the Indian Institute of Technology, Mumbai. Engineering development of this reactor is progressing well and we hope to begin construction in a few years. Meanwhile, development efforts in the fuel cycle area have to match the needs of the emerging reactor programme. This, in fact, has been the case with all activities at BARC.

2.3.5.4. Radiation Technology Applications

Radiation from radio-isotopes and from accelerators has a variety of applications, including health care, agriculture, food preservation, industry and research. Research reactors at Trombay regularly produce a variety of radio-isotopes and meet a major part of the demand in the country. Work on the development of accelerators is being pursued at Centre for Advanced Technologies (CAT), Indore, and at BARC. Development of radiation technology applications is a major thrust area in the R&D programme at BARC. These applications are being commercialized by the Board of Radiation and Isotope Technology (BRIT).

Health Care: Investment in R&D health care resulted in the setting up of a Radiation Medicine Centre has (RMC) as part of BARC in Mumbai, which has become the nucleus for the growth of nuclear medicine in the country. Similarly, Tata Memorial Centre (TMC), a fully autonomous institute aided by the DAE, provides comprehensive treatment for cancer and allied diseases and is one of the best internationally.

To cater to the requirements of the eastern region of the country, a regional radiation medicine centre has been set up at Kolkata as a part of the Variable Energy Cyclotron Centre (VECC).

Agriculture and food: Application of radiation to agriculture has resulted in the release of 22 improved varieties of seeds, which are contributing directly to the increase of GDP in the country. Research done in BARC and other centres in the world, has clearly demonstrated the advantages of food preservation by irradiation, and the Government of India has cleared several items for radiation processing. Setting up of such plants is expected to reduce the percentage of food that is lost due to various causes and provide the means for improving food hygiene and facilitate export.

Industry: Applications of radiation technology for industry span a wide range, including radiography, water hydrology, gamma scanning of process equipment, use of tracers to study sediment transport at ports and harbours, flow measurements, pigging of buried pipelines and water hydrology in general. All these applications are in use and have made significant contributions to Indian industry.

Social Benefits: Over 6,000 technicians have been trained in the use of radiography and they have found employment in India and abroad, where the certification provided by BARC is well recognized. BARC has also developed many applications using electron beam machines, for radiation processing of products such as cross-linking of polyethylene insulation, heat shrinkables, and vulcanization of natural rubber. BARC has developed desalination technologies based on multi-stage flash (MSF) evaporation, reverse osmosis (RO) and low temperature vacuum evaporation.

Technologies to other agencies: While working towards fulfilling its mandate the DAE has developed capabilities in several hi-tech areas which are of interest to other agencies as well. Whenever a request is received for assistance in a field where it has the expertise, DAE provides the help. BARC has completed the development of a finite element based software package specially tailored for rotor dynamic analysis of turbo pumps required for indigenous development of cryo-engines. BARC has provided consultancy to the Department of Ocean Development for recovery of cobalt and nickel from leach liquor obtained by processing of polymetallic nodules. Expertise acquired by BARC in the development of reactor control systems has been also used for providing antenna controls for a number of strategic projects. Similarly, expertise acquired by BARC in non-destructive testing and digital signal processing techniques has been used for the development of a pipe inspection gauge for monitoring the health of cross-country oil pipelines for the Indian Oil Corporation.

2.3.5.5. Basic Research

The DAE places high importance on basic research. All disciplines in nuclear sciences and several science disciplines where nuclear techniques play a role, are covered by this programme, which is broad-based enough to enable use of the DAE facilities by scientists from other organizations as well as provide support to nuclear science activities there. Apart from the four R&D centres BARC, Mumbai; CAT, Indore; VECC, Kolkata; and IGCAR, Kalpakam; there are aided institutions such as Tata Institute of Fundamental Research, Saha Institute of Nuclear Physics, Institute of Physics, Harish-Chandra Research Institute, Institute of Mathematical Sciences, Cancer Research Institute and Institute of Plasma Research, which are engaged in basic research activitites spanning a broad range of disciplines. The DAE also offers several opportunites to scientists from other institutions in India and abroad to interact and collaborate on research activities of mutual interest. The Board of Research in Nuclear Sciences enables such support to Indian scientists, while those from abroad are supported through several bilateral cooperative arrangements or through schemes sponsored by international organizations like the International Atomic Energy Agency in Vienna, the Third World Academy of Sciences in Trieste and others.

Thus, it may be stated that the DAE is manned by trained scientists and engineers, who are relentlessly working towards fulfilling the mandate given to them by the nation, by developing technologies having direct and widespread societal benefits. Nuclear power plants are working well; application of radiation technology to health care is benefiting a large number of patients on a regular basis; improved crop varieties are helping to increase the agricultural output; and radio-isotopes and tracer techniques are helping industry in many ways. It has been able to reach this level because of the broad R&D base that has been nurtured over the years. India is happy to share its experience with scientists from the third world countries and collaborate in areas of mutual interest.

2.3.6. Conclusion

In independent India the new government initiate process of nation building through the establishment of various institute of science and technology. India became a self reliant nation in term of nuclear energy, space technology and other sphere of R & D in science and technology. The Council of Scientific and Industrial Research (CSIR) was founded on 26 September 1942, under the leadership of Dr. Shanti Swarup Bhatnagar (1894-1955), one of the brightest luminaries of Science in India. The government of Independent India setup the Defence Science Organization in 1948 to advise and assist the Defence Services on scientific problems and to undertake research in areas related to defence. Independent India also initiated space research in a vigorous manner. Dr. Sarabhai headed the space research in this period. Establishment of Indian Space Research Organization (ISRO) with headquarters at Ahmedabad, in 1969 opened a new chapter in the area of space research in India. Space technology in India has already established the capacity of high quality research, design, and development in all the fields of space engineering like aeronautics, avionics, and electronics as well as in the processing and manufacture of sophisticated rockets and satellites. The growing energy demand resulted in the origin of India's Atomic Energy programme, which has been a mission oriented comprehensive programme with a long-term focus. Dr. Homi Jahangir Bhabaha was the pioneer in the Indian Nuclear Energy programmme. The Atomic Energy Commission look after the peaceful nuclear programme of India. Indian is also a nuclear power.

2.3.7. Summary

- *During the entire period of British rule, the rulers were content to have the natives only as technical assistants to their scientific explorers in this country.*
- *The British Government, while interested in creating an army of babus-the clerical staff-to assist in the day-to-day administration of the country, were most reluctant to have Indians in the top echelon of any activity.*
- *The educational pattern followed a plan towards this end in view. Study of liberal arts, languages, mathematics, etc. were allowed while technical subjects like the sciences, engineering, etc. were not encouraged.*
- *In such atmosphere also, there were a few bright Indians who realized the importance of science and scientific investigations, and it is their zeal.*
- *European literature on science, industry, and technology; chemicals; and various forms of research equipment slowly found their way into the country.*
- *In the post independent era the new government initiate process of nation building through the establishment of various institute of science and technology.*
- *India became a self reliant nation in term of nuclear energy, space technology and other sphere of R & D in science and technology.*
- *The Council of Scientific and Industrial Research (CSIR) was founded on 26 September 1942, by a resolution of the then Central Legislative Assembly.*
- *It is funded mainly by the India Ministry of Science and Technology and it is one of the world's largest publicly funded (R&D) organizations, having linkages to academia, other R&D organizations and industry.*
- *Dr. Shanti Swarup Bhatnagar (1894-1955), one of the brightest luminaries of Science in India, was the first Director of the Council of Scientific & Industrial Research.*
- *The government of Independent India setup the Defence Science Organization in 1948 to advise and assist the Defence Services on scientific problems and to undertake research in areas related to defence.*

- *The Defence Research & Development Organization (DRDO) was set up in 1958, by merging the units of Defence Science Organization with the then existing Technical Development Establishments of the three Services.*
- *Space research in India, including space science and technology, has a long tradition. The first Indian satellite has been named 'Aryabhata' after the famous mathematician-cum-astronomcr, forging the link between modern India and her glorious past when astronomy and mathematics were used to determine the orientation and configuration of the stars, and to construct platforms for lighting the flies for the well-being of the community.*
- *Establishment of Indian Space Research Organization (ISRO) with headquarters at Ahmedabad, in 1969 opened a new chapter in the area of space research in India.*
- *By the middle of 1972 a separate Department of Space (DOS) and a space commission were created by the Government of India, when ISRO was brought under the new Department.*
- *Space technology in India has already established the capacity of high quality research, design, and development in all the fields of space engineering like aeronautics, avionics, and electronics as well as in the processing and manufacture of sophisticated rockets and satellites.*
- *India's Atomic Energy programme has been a mission oriented comprehensive programme with a long-term focus. Dr. Homi Jahangir Bhabaha was the pioneer in the Indian Nuclear Energy programmme.*
- *The Atomic Energy Commission (AEC) was established in the Department of Atomic Energy is the organ, which look after the peaceful nuclear programme of India.*

2.3.8. Exercise

- Discuss the role of CSIR for the development of modern India in the sphere of R&D.
- Assess the contribution of DRDO for the development of Indian defense research programme.
- Write an essay on the space research programme of India in the pre-independent period.
- Give an account of independent India space research programme under the aegis of ISRO.
- Discuss the nuclear energy programme of modern India.

2.3.9. Further reading

- Angelo , Josepha., The Dictionary of Space Technology. Frederick Muller Ltd., London, 1982.
- Krishnan , K.S., The New Era o f Science. Publications Division, Ministry of Information and Broadcasting, Govt, of India, New Delhi, 1957
- Chatterji , S. Kumar (Ed.), The Cultural Heritage of India. Vol. V. The Ramakrishna Mission Institute of Culture, Calcutta, 1978
- Chattopadhyaya , Debiprasad (Ed.), Studies in the History of Science in India (2 Vols.). Editorial Enterprises, New Delhi, 1982
- Dharampal (Ed.), Indian Science and Technology in the Eighteenth Century: Some Contemporary European Accounts. Im pex India, Delhi, 1971
- Haldane , J . B. S., Science and Indian Culture. New Age Publishers Pvt. Ltd., Calcutta, 1965
- Cohen , Bernard L., Concepts o f Nuclear Physics. Tata McGrow-Hill Publishing Co. Ltd., Bombay, 1971
- Jain , J. P., Nuclear India (2 Vols.). R adiant Publishers, New Delhi, 1974
- Kulkarni , R. P., and Sharma , V., Homi Bhabha: Father o f Nuclear Science in India, Popular Prakashan, Bombay, 1969.
- Subbarayappa, B. V., in Persuit of Excellence, Tata McGraw-Hill, New Delhi. 1992.

*****

Unit-4

Chapter-I

MATHEMATICS AND ASTRONOMY:

Baudhayan, Aryabhtatta, Brahmgupta, Bhaskaracharya, Varahamihira, Nagarjuna

Structure

4.1.0. Objectives

In this lesson, students explore the contribution of various scientists flourished during the ancient period of Indian history. After completing this chapter, you will be able to:

- *trace the life and achievement of Baudhayana, an ancient mathematician;*
- *identify the contribution and influence of Aryabhatta in Indian astronomy;*
- *understand the formula given by Brahmagupta and Bhaskaracharya on ancient Indian astronomy and Mathematics;*
- *assess the role played by Varahamihira and Nagarjuna an ancient Indian astronomy and other ancillary sciences.*

4.1.1. Introduction

Ancient Indian civilization not only flourished itself as the epitome of human civilization in term of growth of literature, philosophy, art and architecture but also different sciences both natural and pure sciences flourished here. The sciences cultivated by learned personalities not by common people. In ancient India great luminaries were born, they cultivated sciences with their personal curiosity under active royal patronization. Some of them such as Baudhayan, Aryabhtatta, Brahmgupta, Bhaskaracharya, Varahamihira and Nagarjuna contributed immensely in the sphere of astronomy and mathematics. The present chapter will discuss each of their contribution in their concerned sphere.

4.1.2. Baudhayana

Baudhayana, (c.800 BCE) was the author of the Baudhayana sutras, which cover dharma, daily ritual, mathematics, etc. He belongs to the Yajurveda school, and is older than the other sutra author Apastamba. He was the author of the earliest Sulba Sutra-appendices to the Vedas giving rules for the construction of altars-called the Baudhayana Sulbasutra. These are notable from the point of view of mathematics, for containing several important mathematical results, including giving a value of *pi* to some degree of precision, and stating a version of what is now known as the Pythagorean theorem. Sequences associated with primitive Pythagorean triples have been named Baudhayana sequences. These sequences have been used in cryptography as random sequences and for the generation of keys.

4.1.2.1. The Sutras of Baudhāyana

The Sutras of Baudhayana are associated with the Taittiriya Sakha (branch) of Krishna (black) Yajurveda. The sutras of Baudhayana have six sections, such as the Srautasutra, probably in nineteen Prasnas (questions), the Karmantasutra in twenty Adhyayas (chapters), the Dvaidhasûtra in 4 Prasnas, the Grihyasutra in four Prasnas, the Dharmasutra in four Prasnas and the Sulbasûtra in three Adhyayas.

The Shrautasutra: His shrauta Sutras related to performing Vedic sacrifices has followers in some Smarta brahmaṇas (Iyers) and some Iyengars and Kongu of Tamil Nadu, Yajurvedis or Namboothiris of Kerala, Gurukkal Brahmins, among others. The followers of this Sutra follow a different method and do twenty four Tila-tarpaṇa, as Lord Krishna had done tarpana on the day before amavasyā; they call themselves Baudhayana Amavasya.

The Dharmasutra: The Dharmasutra of Baudhayana like that of Apastamba also forms a part of the larger Kalpasutra. Likewise, it is composed of prasnas which literally means ‘questions’ or books. The structure of this Dharmasutra is not very clear because it came down in an incomplete manner. Moreover, the text has undergone alterations in the form of additions and explanations over a period of time. The prasnas consist of the Srautasutra and other ritual treatises, the Sulvasutra which deals with vedic geometry, and the Grhyasutra which deals with domestic rituals.

Authorship and Dates: Apastamba and Baudhayana come from the Taittiriya branch vedic school dedicated to the study of the Black Yajurveda. Robert Lingat states that Baudhayana was the first to compose the Kalpasutra collection of the Taittiriya school followed by Apastamba. Kane assigns this Dharmasutra an approximate date between 500 to 200 BC.

Commentaries: There are no commentaries on this Dharmasutra with the exception of Govindasvamin's Vivaraṇa. The date of the commentary is uncertain but according to Olivelle it is not very ancient. Also the commentary is inferior in comparison to that of Haradatta on Apastamba and Gautama.

Organization and Contents: This Dharmasutra is divided into four books. Olivelle states that Book One and the first sixteen chapters of Book Two are the 'Proto-Baudhayana' even though this section has undergone alteration. Scholars like Buhler and Kane agree that the last two books of the Dharmasutra are later additions. Chapter seventeen and eighteen in Book Two lays emphasis on various types of ascetics and acetic practices.

The first book is primarily devoted to the student and deals in topics related to studentship. It also refers to social classes, the role of the king, marriage, and suspension of Vedic recitation. Book two refers to penances, inheritance, women, householder, orders of life, ancestral offerings. Book three refers to holy householders, forest hermit and penances. Book four primarily refers to the yogic practices and penances along with offenses regarding marriage.

4.1.2.2. The Mathematics in Sulbasutra

Pythagorean theorem: The most notable of the rules (the Sulbasutras do not contain any proofs of the rules which they describe, since they are Sutra-s, formulae, concise) in the Baudhayana Sulba Sutra says: *dirghasyaksanaya rajjuh parsvamani, tiryadam mani, cha yatprthagbhute kurutastadubhayaṅ karoti.* A rope stretched along the length of the diagonal produces an area which the vertical and horizontal sides make together.

This appears to be referring to a rectangle, although some interpretations consider this to refer to a square. In either case, it states that the square of the hypotenuse equals the sum of the squares of the sides. If restricted to right-angled isosceles triangles, however, it would constitute a less general claim, but the text seems to be quite open to unequal sides. If this refers to a rectangle, it is the earliest recorded statement of the Pythagorean theorem.

Baudhayana also provides a non-axiomatic demonstration using a rope measure of the reduced form of the Pythagorean theorem for an isosceles right triangle: The cord which is stretched across a square produces an area double the size of the original square.

Circling the square: Another problem tackled by Baudhayana is that of finding a circle whose area is the same as that of a square (the reverse of squaring the circle).

Square root of 2(Two): Baudhayana gives the length of the diagonal of a square in terms of its sides, which is equivalent to a formula for the square root of 2 (Two) as like this the diagonal of a square.

Other theorems include: diagonals of rectangle bisect each other, diagonals of rhombus bisect at right angles, area of a square formed by joining the middle points of a square is half of original, the midpoints of a rectangle joined forms a rhombus whose area is half the rectangle, etc. Note the emphasis on rectangles and squares; this arises from the need to specify yajna bhumikas-i.e. the altar on which a rituals were conducted, including fire offerings (yajna). Apastamba (c. 600 BC) and Katyayana (c. 200 BC), authors of other sulba Sutras, extend some of Baudhayana's ideas. Apastamba provides a more general proof of the Pythagorean theorem.

4.1.3. Aryabhata

Aryabhata or Aryabhata I (476-550 CE) was the first in the line of great mathematician-astronomers from the classical age of Indian mathematics and Indian astronomy. His works include the Aryabhatiya (499 CE, when he was 23 years old) and the Arya-siddhanta.

4.1.3.1. Biography

While there is a tendency to misspell his name as "Aryabhatta" by analogy with other names having the "bhatta" suffix, his name is properly spelled Aryabhata: every astronomical text spells his name thus, including Brahmagupta's references to him "in more than a hundred places by name". Furthermore, in most instances "Aryabhatta" would not fit the metre either.

Time and place of birth: Aryabhata mentions in the Aryabhatiya that it was composed 3,600 years into the Kali Yuga, when he was 23 years old. This corresponds to 499 CE, and implies that he was born in 476. Aryabhata provides no information about his place of birth. The only information comes from Bhaskara I, who describes Aryabhata as asmakiya, "one belonging to the asmaka country." During the Buddha's time, a branch of the Asmaka people settled in the region between the Narmada and Godavari rivers in central India; Aryabhata is believed to have been born there.

It has been claimed that the asmaka (Sanskrit for "stone") where Aryabhata originated may be the present day Kodungallur which was the historical capital city of Thiruvanchikkulam of ancient Kerala. This is based on the belief that Kotunnallur was earlier known as Kotum-Kal-lur ("city of hard stones"). Similarly, the fact that several commentaries on the Aryabhatiya have come from Kerala has been used to suggest that it was Aryabhata's main place of life and activity; however, many commentaries have come from outside Kerala, and the Aryasiddhanta was completely unknown in Kerala. K. Chandra Hari has argued for the Kerala hypothesis on the basis of astronomical evidence. Aryabhata mentions "Lanka" on several occasions in the Aryabhatiya, but his "Lanka" is an abstraction, standing for a point on the equator at the same longitude as his Ujjayini.

Education: It is fairly certain that, at some point, he went to Kusumapura for advanced studies and lived there for some time. Both Hindu and Buddhist tradition, as well as Bhaskara I (CE 629), identify Kusumapura as Pataliputra, modern Patna. A verse mentions that Aryabhata was the head of an institution (kulapa) at Kusumapura, and, because the university of Nalanda was in Pataliputra at the time and had an astronomical observatory, it is speculated that Aryabhata might have been the head of the Nalanda university as well. Aryabhata is also reputed to have set up an observatory at the Sun temple in Taregana, Bihar.

4.1.3.2. Works

Aryabhata is the author of several treatises on mathematics and astronomy, some of which are lost. His major work, Aryabhatiya, a compendium of mathematics and astronomy, was extensively referred to in the Indian mathematical literature and has survived to modern times. The mathematical part of the Aryabhatiya covers arithmetic, algebra, plane trigonometry, and spherical trigonometry. It also contains continued fractions, quadratic equations, sums-of-power series, and a table of sines.

The Arya-siddhanta, a lost work on astronomical computations, is known through the writings of Aryabhata's contemporary, Varahamihira, and later mathematicians and commentators, including Brahmagupta and Bhaskara I. This work appears to be based on the older Surya Siddhanta and uses the midnight-day reckoning, as opposed to sunrise in Aryabhatiya. It also contained a description of several astronomical instruments: the gnomon (shanku-yantra), a shadow instrument (chhaya-yantra), possibly angle-measuring devices, semicircular and circular (dhanur-yantra/chakra-yantra), a cylindrical stick yasti-yantra, an umbrella-shaped device called the chhatra-yantra, and water clocks of at least two types, bow-shaped and cylindrical.

A third text, which may have survived in the Arabic translation, is Al-nanf. It claims that it is a translation by Aryabhata, but the Sanskrit name of this work is not known. Probably dating from the 9th century, it is mentioned by the Persian scholar and chronicler of India, Abu Rayhan al-Biruni.

Aryabhatiya: Direct details of Aryabhata's work are known only from the Aryabhatiya. The name "Aryabhatiya" is due to later commentators. Aryabhata himself may not have given it a name. His disciple Bhaskara I calls it Ashmakatantra (or the treatise from the Ashmaka). It is also occasionally referred to as Arya-shatas-ashta (literally, Aryabhata's 108), because there are 108 verses in the text. It is written in the very terse style typical of sutra literature, in which each line is an aid to memory for a complex system. Thus, the explication of meaning is due to commentators. The text consists of the 108 verses and 13 introductory verses, and is divided into four padas or chapters:

1. Gitikapada: (13 verses): large units of time-kalpa, manvantra, and yuga-which present a cosmology different from earlier texts such as Lagadha's Vedanga Jyotisha (c. 1st century BCE). There is also a

table of sines (jya), given in a single verse. The duration of the planetary revolutions during a mahayuga is given as 4.32 million years.

2. Ganitapada (33 verses): covering mensuration (ksetra vyavahara), arithmetic and geometric progressions, gnomon / shadows (shanku-chhaya), simple, quadratic, simultaneous, and indeterminate equations (kuttaka).
3. Kalakriyapada (25 verses): different units of time and a method for determining the positions of planets for a given day, calculations concerning the intercalary month (adhikamasa), kshaya-tithis, and a seven-day week with names for the days of week.
4. Golapada (50 verses): Geometric/trigonometric aspects of the celestial sphere, features of the ecliptic, celestial equator, node, shape of the earth, cause of day and night, rising of zodiacal signs on horizon, etc. In addition, some versions cite a few colophons added at the end, extolling the virtues of the work, etc.

The Aryabhatiya presented a number of innovations in mathematics and astronomy in verse form, which were influential for many centuries. The extreme brevity of the text was elaborated in commentaries by his disciple Bhaskara I (Bhashya, c. 600 CE) and by Nilakantha Somayaji in his Aryabhatiya Bhasya, (1465 CE).

4.1.3.3. Mathematics

Place value system and zero: The place-value system, first seen in the 3rd-century Bakhshali Manuscript, was clearly in place in his work. While he did not use a symbol for zero, the French mathematician Georges Ifrah argues that knowledge of zero was implicit in Aryabhata's place-value system as a place holder for the powers of ten with null coefficients. However, Aryabhata did not use the Brahmi numerals. Continuing the Sanskritic tradition from Vedic times, he used letters of the alphabet to denote numbers, expressing quantities, such as the table of sines in a mnemonic form.

Approximation of π: Aryabhata worked on the approximation for pi ( ), and may have come to the conclusion that is irrational. In the second part of the Aryabhatiyam (gaṇitapada 10), he writes: "Add four to 100, multiply by eight, and then add 62,000. By this rule the circumference of a circle with a diameter of 20,000 can be approached."

This implies that the ratio of the circumference to the diameter is $((4 + 100) \times 8 + 62000)/20000 = 62832/20000 = 3.1416$, which is accurate to five significant figures.

It is speculated that Aryabhata used the word asanna (approaching), to mean that not only is this an approximation but that the value is incommensurable (or irrational). If this is correct, it is quite a sophisticated insight, because the irrationality of pi was proved in Europe only in 1761 by Lambert. After Aryabhatiya was translated into Arabic (c. 820 CE) this approximation was mentioned in Al-Khwarizmi's book on algebra.

Trigonometry: In Ganitapada 6, Aryabhata gives the area of a triangle as '*tribhujasya phalashariram samadalakoti bhujardhasamvargah'* that translates to: "for a triangle, the result of a perpendicular with the half-side is the area."

Aryabhata discussed the concept of sine in his work by the name of ardha-jya, which literally means "half-chord". For simplicity, people started calling it jya. When Arabic writers translated his works from Sanskrit into Arabic, they referred it as jiba. However, in Arabic writings, vowels are omitted, and it was abbreviated as jb. Later writers substituted it with jaib, meaning "pocket" or "fold (in a garment)". (In Arabic, jiba is a meaningless word.) Later in the 12th century, when Gherardo of Cremona translated these writings from Arabic into Latin, he replaced the Arabic jaib with its Latin counterpart, sinus, which means "cove" or "bay"; thence comes the English word sine.

Indeterminate equations: A problem of great interest to Indian mathematicians since ancient times has been to find integer solutions to Diophantine equations that have the form $ax + by = c$. This is an example from Bhaskara's commentary on Aryabhatiya: Find the number which gives 5 as the remainder when divided by 8, 4 as the remainder when divided by 9, and 1 as the remainder when divided by 7. That is, find N = 8x+5 = 9y+4 = 7z+1. It turns out that the smallest value for N is 85. In general, diophantine equations, such as this, can be notoriously difficult. They were discussed extensively in ancient Vedic text Sulba Sutras, whose more ancient parts might date to 800 BCE. Aryabhata's method of solving such problems, elaborated by Bhaskara in 621 CE, is called the kuttaka method. Kuttaka means "pulverizing" or "breaking into small pieces", and the method involves a recursive algorithm for writing the original factors in smaller numbers. This algorithm became the standard method for solving first-order diophantine equations in Indian mathematics, and initially the whole subject of algebra was called kuttaka-ganita or simply kuttaka.

Algebra: In Aryabhatiya, Aryabhata provided elegant results for the summation of series of squares and cubes:

4.1.3.4. Astronomy

Aryabhata's system of astronomy was called the audayaka system, in which days are reckoned from uday, dawn at lanka or "equator". Some of his later writings on astronomy, which apparently proposed a second model (or ardharatrika, midnight) are lost but can be partly reconstructed from the discussion in Brahmagupta's khandakhadyaka. In some texts, he seems to ascribe the apparent motions of the heavens to the Earth's rotation. He may have believed that the planet's orbits as elliptical rather than circular.

Motions of the solar system: Aryabhata correctly insisted that the earth rotates about its axis daily, and that the apparent movement of the stars is a relative motion caused by the rotation of the earth, contrary to the then-prevailing view, that the sky rotated. This is indicated in the first chapter of the Aryabhatiya, where he gives the number of rotations of the earth in a yuga, and made more explicit in his gola chapter: In the same way that someone in a boat going forward sees an unmoving [object] going backward, so [someone] on the equator sees the unmoving stars going uniformly westward. The cause of rising and setting [is that] the sphere of the stars together with the planets [apparently] turns due west at the equator, constantly pushed by the cosmic wind.

Aryabhata described a geocentric model of the solar system, in which the Sun and Moon are each carried by epicycles. They in turn revolve around the Earth. In this model, which is also found in the Paitamahasiddhanta (c. CE 425), the motions of the planets are each governed by two epicycles, a smaller manda (slow) and a larger sighra (fast). The order of the planets in terms of distance from earth is taken as: the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the asterisms."

The positions and periods of the planets was calculated relative to uniformly moving points. In the case of Mercury and Venus, they move around the Earth at the same mean speed as the Sun. In the case of Mars, Jupiter, and Saturn, they move around the Earth at specific speeds, representing each planet's motion through the zodiac. Most historians of astronomy consider that this two-epicycle model reflects elements of pre-Ptolemaic Greek astronomy. Another element in Aryabhata's model, the Sighrocca, the basic planetary period in relation to the Sun, is seen by some historians as a sign of an underlying heliocentric model.

Eclipses: Solar and lunar eclipses were scientifically explained by Aryabhata. He states that the Moon and planets shine by reflected sunlight. Instead of the prevailing cosmogony in which eclipses were caused by Rahu and Ketu (identified as the pseudo-planetary lunar nodes), he explains eclipses in terms of shadows cast by and falling on Earth. Thus, the lunar eclipse occurs when the moon enters into the Earth's shadow (verse gola.37). He discusses at length the size and extent of the Earth's shadow (verses gola.38-48) and then provides the computation and the size of the eclipsed part during an eclipse. Later Indian astronomers improved on the calculations, but Aryabhata's methods provided the core. His computational paradigm was so accurate that 18th-century scientist Guillaume Le Gentil, during a visit to Pondicherry, India, found the Indian computations of the duration of the lunar eclipse of 30 August 1765 to be short by 41 seconds, whereas his charts were long by 68 seconds.

Sidereal periods: Considered in modern English units of time, Aryabhata calculated the sidereal rotation (the rotation of the earth referencing the fixed stars) as 23 hours, 56 minutes, and 4.1 seconds; the modern value is 23:56:4.091. Similarly, his value for the length of the sidereal year at 365 days, 6 hours, 12 minutes, and 30 seconds (365.25858 days) is an error of 3 minutes and 20 seconds over the length of a year (365.25636 days).

Heliocentrism: As mentioned, Aryabhata advocated an astronomical model in which the Earth turns on its own axis. His model also gave corrections (the sigra anomaly) for the speeds of the planets in the sky in terms of the mean speed of the sun. Thus, it has been suggested that Aryabhata's calculations were based on an underlying heliocentric model, in which the planets orbit the Sun, though this has been rebutted. It has also been suggested that aspects of Aryabhata's system may have been derived from an earlier, likely pre-Ptolemaic Greek, heliocentric model of which Indian astronomers were unaware, though the evidence is scant. The general consensus is that a synodic anomaly (depending on the position of the sun) does not imply a physically heliocentric orbit (such corrections being also present in late Babylonian astronomical texts), and that Aryabhata's system was not explicitly heliocentric.

4.1.3.5. Legacy

Aryabhata's work was of great influence in the Indian astronomical tradition and influenced several neighbouring cultures through translations. The Arabic translation during the Islamic Golden Age (c. 820 CE), was particularly influential. Some of his results are cited by Al-Khwarizmi and in the 10th century Al-Biruni stated that Aryabhata's followers believed that the Earth rotated on its axis.

His definitions of sine (jya), cosine (kojya), versine (utkrama-jya), and inverse sine (otkram jya) influenced the birth of trigonometry. He was also the first to specify sine and versine (1 - cos x) tables, in 3.75° intervals from 0° to 90°, to an accuracy of 4 decimal places. In fact, modern names "sine" and "cosine" are mis-transcriptions of the words jya and kojya as introduced by Aryabhata. As mentioned, they were translated as jiba and kojiba in Arabic and then misunderstood by Gerard of Cremona while translating an Arabic geometry text to Latin. He assumed that jiba was the Arabic word jaib, which means "fold in a garment", L. sinus (c. 1150).

Aryabhata's astronomical calculation methods were also very influential. Along with the trigonometric tables, they came to be widely used in the Islamic world and used to compute many Arabic astronomical tables (zijes). In particular, the astronomical tables in the work of the Arabic Spain scientist Al-Zarqali (11th century) were translated into Latin as the Tables of Toledo (12th century) and remained the most accurate ephemeris used in Europe for centuries.

Calendric calculations devised by Aryabhata and his followers have been in continuous use in India for the practical purposes of fixing the Panchangam (the Hindu calendar). In the Islamic world, they formed the basis of the Jalali calendar introduced in 1073 CE by a group of astronomers including Omar Khayyam, versions of which (modified in 1925) are the national calendars in use in Iran and Afghanistan today. The dates of the Jalali calendar are based on actual solar transit, as in Aryabhata and earlier Siddhanta calendars. This type of calendar requires an ephemeris for calculating dates. Although dates were difficult to compute, seasonal errors were less in the Jalali calendar than in the Gregorian calendar.

Aryabhatta Knowledge University (AKU), Patna has been established by Government of Bihar for the development and management of educational infrastructure related to technical, medical, management and allied professional education in his honour. The university is governed by Bihar State University Act 2008.

India's first satellite Aryabhata and the lunar crater Aryabhata are named in his honour. An Institute for conducting research in astronomy, astrophysics and atmospheric sciences is the Aryabhatta Research Institute of Observational Sciences (ARIES) near Nainital, India. The inter-school Aryabhata Maths Competition is also named after him, as is Bacillus aryabhata, a species of bacteria discovered by ISRO scientists in 2009.

4.1.4. Brahmagupta

Brahmagupta holds a unique position in the history of Ancient Indian Mathematics. He contributed such elegant results to Geometry and Number Theory that today's mathematicians still marvel at their originality. His theorems leading to the calculation of the circum-radius of a triangle and the lengths of the diagonals of a cyclic quadrilateral, construction of a rational cyclic quadrilateral and integer solutions to a single second degree equation are certainly the hallmarks of a genius.

After the Greeks' ascendancy to supremacy in mathematics (especially geometry) during the period 7th century BC to 2nd century AD, there was a sudden lull in mathematical and scientific activity for the next millennium until the Renaissance in Europe. But mathematics and astronomy flourished in the Asian continent particularly in India and the Arab world. There was a continuous exchange of information between the two regions and later between Europe and the Arab world. The decimal representation of positive integers along with zero, a unique contribution of the Indian mind, travelled eventually to the West, although there was some resistance and reluctance to accept it at the beginning.

4.1.4.1. Biography and brief achievements

He was born in a village called Bhillamala in North West Rajasthan in the year 598 AD . He spent his early days as court astronomer to King Vyaghramukha. He is best known for his seminal text, the Bahmasphutasiddhanata (628, The Opening of the Universe) or simply the Siddhanta. He wrote a second book Khandakhadyaka later. The first book contains 1008 slokas (verses) in 25 chapters and deals with arithmetic, algebra, geometry and number theory. He was the First to introduce zero as a digit. This was translated into Arabic with the title Sindhind. The second book has 194 slokas and deals with astronomical calculations in 9 chapters. He was certainly a mathematician of preeminence for his times, but he also had the habit of criticising his predecessors sharply for some of their faults and omissions. There is a sequel to his second book which deals with some corrections of his earlier work. He was the head of Ujjain observatory. He passed away in the year 668 AD.

4.1.4.2. Brahmagupta's Contributions: Mathematics

Brahmagupta holds a unique position in the history of Ancient Indian Mathematics. He contributed much towards astronomy also. Following are some of his notable works and contribution:

Algebra:The following rules for algebra given by Brahmagupta should be familiar except for terminology, although he incorrectly claimed that zero divided by zero is zero. 1. A debt minus zero is a debt. 2. A fortune minus zero is a fortune. 3. Zero minus zero is zero. 4. A debt subtracted from zero is a fortune. 5. A fortune subtracted from zero is a debt. 6. The product of zero multiplied by a debt or a fortune is zero. 7. The product of zero multiplied by zero is zero. 8. The product or quotient of two fortunes is a fortune. 9. The product or quotient of two debts is a fortune. 10. The product or quotient of a debt and a fortune is a debt. 11. The product or quotient of a fortune and a debt is a debt.

Other Theorem: In addition, Brahmagupta gave a method of solving indeterminate equations of the second degree, and rules for solving simple quadratic equations of various types. Some of them are as follows:

1. Brahmagupta gave a general formula for the so called Pythagorean triples.

2. Given a side a of a right-angled triangle other than the hypotenuse, a formula was given for the sides of the triangle and Given the hypotenuse c, of a right-angled triangle, the sides are given by c; 2mnc These result in rational right triangles.

3. Given a rational altitude x of a triangle, if the sides are given by a , then we have a scalene triangle with rational sides, rational area and rational altitudes (and rational circum radius).

4. The product of any two sides of a triangle is equal to the product of its circum-diameter and altitude drawn on the third side. This result which is easily proved by similarity of triangles leads to a formula for the circum radius of a triangle.

5. The area of a (cyclic) quadrilateral with sides a; b; c; d and semi-perimeter s is p and the diagonals of a cyclic quadrilateral with sides a; b; c; d are q (ab+cadd)+(abc+bd) and q(ad+abcb)+(acdc+bd) .

7. Integer cyclic quadrilaterals: Brahmagupta gave a simple method to construct cyclic quadrilaterals with integer sides, integer diagonals and integer area. Take two different (non-similar) right-angled triangles with sides (a; b; c) and (x; y; z), where c and z are the hypotenuses. Magnify the first by factors of x and y to get two triangles and the second by factors of a and b to get two more triangles. Assemble these four right

triangles so that the O's, A's, B's, C's and D's coincide. Then we have a cyclic quadrilateral ABCD with integer sides bz; cy; az; cx and integer diagonals ay + bx; ax+by and integer area 12(ax+by)(ay+bx).

This single marvelous result needs a little elaboration. The integer quadrilateral constructed by Brahmagupta has perpendicular diagonals. Do there exist integer cyclic quadrilaterals with non-orthogonal diagonals? In the 19th century AD, Kummer, a German mathematician found all rational cyclic quadrilaterals. For this one needs to start with two non-similar triangles, the sines and cosines of whose angles are all rational. Further the circum-radius of such quadrilaterals also turns out to be rational!

8. Brahmagupta gave a beautiful method to generate infinitely many integer solutions of the single equation Nx2+1 = y2, where N is a non-square integer, starting with one trial solution. This feat was achieved by Bhaskara II of 12th century AD. In fact he found that (x; y) = (223 153 980; 1766 319 049) was the smallest solution of 61x2 + 1 = y2. The method used to obtain a solution is called `chakravala'.

These equations were later explored by European mathematicians thoroughly and now there is a rich and interesting theory created by number-theorists. Continued fractions play a big role in this. Brahmagupta's contribution to second-order interpolation for ¯nding sine ratios accurately also deserves a mention. The readers may note that the seeds of trigonometry were sown in India. Brahmagupta gave formulae for the sum of squares and cubes of ¯rst n natural numbers. He also solved the general quadratic equation.

Bhaskara II aptly gave the title `Ganakachakra Chudamani' to Brahmagupta. While mathematics was described as the jewel of all sciences, Brahmagupta accordingly deserves to be described as `a brightest star in the galaxy of mathematicians'.

4.1.4.3. Brahmagupta's Contributions: Astronomy

When Brahmagupta was 67, he wrote the Khandakhadyaka, literally meaning “sweetmeat.” With it, he became the first to use algebra to solve astronomical problems. He anticipated the gravitational theory, writing: “Bodies fall towards the earth as it is the nature of earth to attract bodies, just as it is the nature of water to flow.” He gave the sidereal periods for many heavenly bodies, including the sun, which he claimed, made 30 circuits of the ecliptic in 10,960 days; that is, the sun moves 3/1096 of a sidereal year every day. He then imagined the ecliptic divided into 10,960 congruent arcs, with the sun at the beginning of the first arc if the first day of a 10,960-day cycle. He offered no proofs of his results, but this shouldn’t be taken as a sign that he was unaware of the nature of proof or the need to demonstrate the validity of the rules. His works were intended as algorithms for solving a variety of problems, mostly relating to astronomy and astrology, and he likely didn’t feel that those who would use them needed proofs. With the spread of Buddhism around 500 CE, Chinese scholars became acquainted with the Siddhanta, and made translations. Of greater significance in terms of his influence, were the Arabic translations.: Brahmagupta said “As the sun eclipses the stars by his brilliancy, so the man of knowledge will eclipse the fame of others in assemblies of the people if he proposes algebraic problems, and still more if he solves them.”

4.1.5. Bhaskaracharya

The period between 500 and 1200 AD was the golden age of Indian Astronomy. In this long span of time Indian Astronomy flourished mainly due to eminent astronomers like Aryabhat, Lallacharya, Varahamihir, Brahmagupta, Bhaskaracharya and others. Bhaskaracharya’s Siddhanta Shiromani is considered as the pinnacle of all the astronomical works of those 700 hundred years. It can be aptly called the “essence” of ancient Indian Astronomy and mathematics. In the ninth century Brahmagupta’s Brahmasphutasiddhanta was translated in Arabic. The title of the translation was ‘Sind Hind’. This translation proved to be a watershed event in the history of numbers. The Arabs quickly grasped the importance of the Indian decimal system of numbers. They played a key role in transmitting this system of numbers to Europeans.

4.1.5.1. Birth and Education of Bhaskaracharya :

Ganesh Daivadnya has bestowed a very apt title on Bhaskaracharya. He has called him ‘Ganakchakrachudamani’, which means, ‘a gem among all the calculators of astronomical phenomena.’ Bhaskaracharya himself has written about his birth, his place of residence, his teacher and his education, in

Siddhantashiromani as follows, ‘ A place called ‘Vijjadveed’, which is surrounded by Sahyadri ranges, where there are scholars of three Vedas, where all branches of knowledge are studied, and where all kinds of noble people reside, a brahmin called Maheshwar was staying, who was born in Shandilya Gotra (in Hindu religion, Gotra is similar to lineage from a particular person, in this case sage Shandilya), well versed in Shroud (originated from ‘Shut’ or ‘Vedas’) and ‘Smart’ (originated from ‘Smut’) Dharma, respected by all and who was authority in all the branches of knowledge. I acquired knowledge at his feet’.

From this verse it is clear that Bhaskaracharya was a resident of Vijjadveed and his father Maheshwar taught him mathematics and astronomy. Unfortunately today we have no idea where Vijjadveed was located. It is necessary to ardently search this place which was surrounded by the hills of Sahyadri and which was the center of learning at the time of Bhaskaracharya. He writes about his year of birth as follows,

‘I was born in Shaka 1036 (1114 AD) and I wrote Siddhanta Shiromani when I was 36 years old.’ Bhaskaracharya has also written about his education. Looking at the knowledge, which he acquired in a span of 36 years, it seems impossible for any modern student to achieve that feat in his entire life. See what Bhaskaracharya writes about his education, ‘I have studied eight books of grammar, six texts of medicine, six books on logic, five books of mathematics, four Vedas, five books on Bharat Shastras, and two Mimansas’. Bhaskaracharya calls himself a poet and most probably he was Vedanti, since he has mentioned ‘Parambrahman’ in that verse.

4.1.5.2. Siddhanta Shiromani

Bhaskaracharya wrote Siddhanta Shiromani in 1150 AD when he was 36 years old. This is a mammoth work containing about 1450 verses. It is divided into four parts, Lilawati, Beejaganit, Ganitadhyaya and Goladhyaya. In fact each part can be considered as separate book. The numbers of verses in each part are as follows, Lilawati has 278, Beejaganit has 213, Ganitadhyaya has 451 and Goladhyaya has 501 verses. One of the most important characteristic of Siddhanta Shiromani is, it consists of simple methods of calculations from Arithmetic to Astronomy. Essential knowledge of ancient Indian Astronomy can be acquired by reading only this book. Siddhanta Shiromani has surpassed all the ancient books on astronomy in India. After Bhaskaracharya nobody could write excellent books on mathematics and astronomy in lucid language in India. In India, Siddhanta works used to give no proofs of any theorem.

Bhaskaracharya has also followed the same tradition. Lilawati is an excellent example of how a difficult subject like mathematics can be written in poetic language. Lilawati has been translated in many languages throughout the world. When British Empire became paramount in India, they established three universities in 1857, at Bombay, Calcutta and Madras. Till then, for about 700 years, mathematics was taught in India from Bhaskaracharya’s Lilawati and Beejaganit. No other textbook has enjoyed such long lifespan.

4.1.5.3. Bhaskar’s Mathematics

Lilawati and Beejaganit together consist of about 500 verses. A few important highlights of Bhaskar’s mathematics are as follows, Terms for numbers In English, cardinal numbers are only in multiples of 1000. They have terms such as thousand, million, billion, trillion, quadrillion etc. Most of these have been named recently. However, Bhaskaracharya has given the terms for numbers in multiples of ten and he says that these terms were coined by ancients for the sake of positional values. Bhaskar’s terms for numbers are as follows: eka(1), dasha(10), shata(100), sahastra(1000), ayuta(10,000), laksha(100,000), prayuta (1,000,000=million), koti(107), arbuda(108), abja(109=billion), kharva (1010), nikharva (1011), mahapadma (1012=trillion), shanku(1013), jaladhi(1014), antya(1015=quadrillion), Madhya (1016) and parardha(1017).

Kuttak: Kuttak is nothing but the modern indeterminate equation of first order. The method of solution of such equations was called as ‘pulverizer’ in the western world. Kuttak means to crush to fine particles or to pulverize. There are many kinds of Kuttaks. Indian Astronomers used such kinds of equations to solve astronomical problems. It is not easy to find solutions of these equations but Bhaskara has given a generalized solution to get multiple answers.

Chakrawaal:Chakrawaal is the “indeterminate equation of second order” in western mathematics. This type of equation is also called Pell’s equation. Though the equation is recognized by his name Pell had ever solved the equation. Much before Pell, the equation was solved by an ancient and eminent Indian mathematician, Brahmagupta (628 AD). The solution is given in his Brahmasphutasiddhanta. Bhaskara modified the method and gave a general solution of this equation..

Simple Mathematical Methods: Bhaskara has given simple methods to find the squares, square roots, cube, and cube roots of big numbers. He has proved the Pythagoras theorem in only two lines. The famous Pascal Triangle was Bhaskara's 'Khandameru'. Bhaskara has given problems on that number triangle. Pascal was born 500 years after Bhaskara. Several problems on permutations and combinations are given in Lilawati. Bhaskar. He has called the method 'ankapaash'. Bhaskara has given an approximate value of PI as 22/7 and more accurate value as 3.1416. He knew the concept of infinity and called it as 'khahar rashi', which means 'anant'. It seems that Bhaskara had not notions about calculus.

4.1.5.4. Bhaskar's Astronomy

Ganitadhyaya and Goladhyaya of Siddhanta Shiromani are devoted to astronomy. All put together there are about 1000 verses. Almost all aspects of astronomy are considered in these two books. Some of the highlights are worth mentioning. Earth's circumference and diameter Bhaskara has given a very simple method to determine the circumference of the Earth. According to this method, first find out the distance between two places, which are on the same longitude. Then find the correct latitudes of those two places and difference between the latitudes. Knowing the distance between two latitudes, the distance that corresponds to 360 degrees can be easily found, which the circumference of is the Earth. For example, Satara and Kolhapur are two cities on almost the same longitude. The difference between their latitudes is one degree and the distance between them is 110 kilometers. Then the circumference of the Earth is 110 X 360 = 39600 kilometers. Once the circumference is fixed it is easy to calculate the diameter. Bhaskara gave the value of the Earth's circumference as 4967 'yojane' (1 yojan = 8 km), which means 39736 kilometers. His value of the diameter of the Earth is 1581 yojane i.e. 12648 km. The modern values of the circumference and the diameter of the Earth are 40212 and 12800 kilometers respectively. The values given by Bhaskara are astonishingly close.

For astronomical calculations, Bhaskara selected a set of eight right angle triangles, similar to each other. The triangles are called 'aksha kshetre'. One of the angles of all the triangles is the local latitude. If the complete information of one triangle is known, then the information of all the triangles is automatically known. Out of these eight triangles, complete information of one triangle can be obtained by an actual experiment. Then using all eight triangles virtually hundreds of ratios can be obtained. This method can be used to solve many problems in astronomy.

Geocentric Parallax: Ancient Indian Astronomers knew that there was a difference between the actual observed timing of a solar eclipse and timing of the eclipse calculated from mathematical formulae. This is because calculation of an eclipse is done with reference to the center of the Earth, while the eclipse is observed from the surface of the Earth. The angle made by the Sun or the Moon with respect to the Earth's radius is known as parallax. Bhaskara knew the concept of parallax, which he has termed as 'lamban'. He realized that parallax was maximum when the Sun or the Moon was on the horizon, while it was zero when they were at zenith. The maximum parallax is now called Geocentric Horizontal Parallax. By applying the correction for parallax exact timing of a solar eclipse from the surface of the Earth can be determined.

Yantradhyay: In this chapter of Goladhyay, Bhaskar has discussed eight instruments, which were useful for observations. The names of these instruments are, Gol yantra (armillary sphere), Nadi valay (equatorial sun dial), Ghatika yantra, Shanku (gnomon), Yashti yantra, Chakra, Chaap, Turiya, and Phalak yantra. Out of these eight instruments Bhaskara was fond of Phalak yantra, which he made with skill and efforts. He argued that ' this yantra will be extremely useful to astronomers to calculate accurate time and understand many astronomical phenomena'. Bhaskara's Phalak yantra was probably a precursor of the 'astrolabe' used during medieval times.

Dhee yantra: This instrument deserves to be mentioned specially. The word 'dhee' means ' Buddhi' i.e. intelligence. The idea was that the intelligence of human being itself was an instrument. If an intelligent person gets a fine, straight and slender stick at his/her disposal he/she can find out many things just by using that stick. Here Bhaskara was talking about extracting astronomical information by using an ordinary stick. One can use the stick and its shadow to find the time, to fix geographical north, south, east, and west. One can find the latitude of a place by measuring the minimum length of the shadow on the equinoctial days or pointing the stick towards the North Pole. One can also use the stick to find the height and distance of a tree even if the tree is beyond a lake.

4.1.5.5. A Glance at the Astronomical Achievements of Bhaskaracharya

- The Earth is not flat, has no support and has a power of attraction.
- The north and south poles of the Earth experience six months of day and six months of night.
- One day of Moon is equivalent to 15 earth-days and one night is also equivalent to 15 earth-days.
- Earth's atmosphere extends to 96 kilometers and has seven parts.
- There is a vacuum beyond the Earth's atmosphere.
- He had knowledge of precession of equinoxes. He took the value of its shift from the first point of Aries as 11 degrees. However, at that time it was about 12 degrees.
- Ancient Indian Astronomers used to define a reference point called 'Lanka'. It was defined as the point of intersection of the longitude passing through Ujjaini and the equator of the Earth. Bhaskara has considered three cardinal places with reference to Lanka, the Yavakoti at 90 degrees east of Lanka, the Romak at 90 degrees west of Lanka and Siddhapoor at 180 degrees from Lanka. He then accurately suggested that, when there is a noon at Lanka, there should be sunset at Yavkoti and sunrise at Romak and midnight at Siddhapoor.

Bhaskaracharya had accurately calculated apparent orbital periods of the Sun and orbital periods of Mercury, Venus, and Mars. There is slight difference between the orbital periods he calculated for Jupiter and Saturn and the corresponding modern values. About 800 years back an intelligent mathematician and astronomer was born in India. The concepts and methods developed by Bhaskaracharya are relevant even today.

4.1.6. Varahamihira (505–587 CE)

Varahamihira belonged to the galaxy of Indi**a**n scientists that included Dhanvantari, Chakara, Susruta, Aryabhata, and Bhaskaracharya whose fields of specialization ranged from medicine to surgery, mathematics, and meteorology. Varahamihira was unique in that he had astonishing knowledge of a variety of subjects like hydrology, meteorology, astrology, astronomy, and seismology. His magnum opus is Brihat Samhita, which deals with all these subjects. Alberuni, the Arabian scholar, translated another work of Varahamihira, Brihat Jataka into Arabic and he eulogised Varahamihira for his Brihat Samhita for its richness in detail. Varahamihira belonged to Ujjain (AD 505-587). He respected learning wherever it was found and was intimately acquainted with astrological literature of the Greeks to whom he made reference in his works. His other works included Pancha Siddhantika, Vivahapatala, Laghujataka, Yatra, possibly written in that order. He was born in Avanti region, roughly corresponding to modern-day Malwa, to Adityadasa, who was himself an astronomer. According to one of his own works, he was educated at Kapitthaka. He is considered to be one of the nine jewels (Navaratnas) of the court of legendary ruler Yashodharman Vikramaditya of Malwa.

4.1.6.1. Works

He was the first one to mention in his work Pancasiddhantika that the ayanamsa, or the shifting of the equinox, is 50.32 seconds.

Pancha-Siddhantika: Varahamihira's main work is the book Pancasiddhantika a treatise on the five a astronomical Canons dated ca. 575 CE gives us information about older Indian texts which are now lost. The work is a treatise on mathematical astronomy and it summarises five earlier astronomical treatises, namely the Surya Siddhanta, Romaka Siddhanta, Paulisa Siddhanta, Vasishtha Siddhanta and Paitamaha Siddhantas. It is a compendium of Vedanga Jyotisha as well as Hellenistic astronomy (including Greek, Egyptian and Roman elements). He was the first one to mention in his work Pancha Siddhantika that the ayanamsa, or the shifting of the equinox is 50.32 seconds. The 11th century Iranian scholar Alberuni also described the details of "The Five Astronomical Canons".

***Brihat-Samhita**:* Another important contribution of Varahamihira is the encyclopedic Brihat-Samhita. It covers wide ranging subjects of human interest, including astrology, planetary movements, eclipses, rainfall, clouds, architecture, growth of crops, manufacture of perfume, matrimony, domestic relations, gems, pearls, and rituals. The volume expounds on gemstone evaluation criterion found in the Garuda Purana, and elaborates on the sacred Nine Pearls from the same text. It contains 106 chapters and is known as the "great compilation". The Brihat Samhita, a work on Samhita consists of 106 characters with a totla of nearly 4000 slokas (verses in Sanskrit). The range of subjects dealt with is very large, including the effects of movements of the planets and natural phenomena on human life, geography, characteristics of Khadga (sword), Angavidya, architecture, iconography, auspicious and inauspicious characteristics of people and animals, omens, manufacture of cosmetics, botany, and science of precious stones (gemmology). Chapters XXI to XXXIX are geophysical in nature and mainly deal with meteorology. The subjects dealt with are cloud formation, rainfall and its quantity, the appropriate planetary conjuctions, signs of immediate rain, hurricanes, etc. Sloka 5 says: the symptoms of pregnancy of clouds are to be determined when the moon transits the star Parvashadha commnencing from the first day of Margasira (approximately December). Sloka 6: the foetus formed during the moon's stay in a particular asterism will be born 195 days hence, thew moon standing again in the same asterism according to the laws of her revolution. Slokas 9-12: these point out that clouds formed in the first half of Chaitra (March – April) will yield water in the latter half of Aswayuja (October) and those that are formed in the latter half of Chaitra will rain in the first half of Kartika (November). These concepts seem to have been in vogue during the Rg Veda period too (JRAS, 1871). Rain-gauging appears to have been prevalent in India from very early times and the earliest reference to it is to be found in Panini's Astadhyayi. According to Varahamihira, rain should be measured after the fool moon day of the month of Jyestha (May-June) when it has rained in the asterism commencing with Purvasadha.

On Astrology: He was also an astrologer. He wrote on all the three main branches of Jyotisha astrology includes Brihat Jataka - is considered as one of the five main treatises on Hindu astrology on horoscopy, Laghu Jataka - also known as 'Swalpa Jataka', Samasa Samhita - also known as 'Lagu Samhita' or 'Swalpa Samhita', Brihat Yogayatra - also known as 'Mahayatra' or 'Yakshaswamedhiya yatra', Yoga Yatra - also known as 'Swalpa yatra', Tikkani Yatra, Brihat Vivaha Patal, Lagu Vivaha Patal - also known as 'Swalpa Vivaha Patal', Lagna Varahi, Kutuhala Manjari and Daivajna Vallabha (apocryphal)

His son Prithuyasas also contributed in the Hindu astrology; his book Hora Sara is a famous book on horoscopy. Khana (also named Lilavati elsewhere) the medieval Bengali poetess astrologer is believed to be the daughter-in-law of Varahamihir.

4.1.6.2. Western influences

The Romaka Siddhanta ("Doctrine of the Romans") and the Paulisa Siddhanta ("Doctrine of Paul") were two works of Western origin which influenced Varahamihira's thought, though this view is controversial as there is much evidence to suggest that it was actually Vedic thought indigenous to India which first influenced Western astrologers and subsequently came back to India reformulated. A comment in the Brihat-Samhita by Varahamihira says: "The Greeks, though barbarians., must be honored since they have shown tremendous interest in our science....." ("mleccha hi yavanah tesu samyak shastram kaamsthitam/ rsivattepi pujyante kim punar daivavid dvijah" (Brihat-Samhita 2.15)).

4.1.6.3. Contributions

Trigonometry: Varahamihira's mathematical work included the discovery of the trigonometric formulas Varahamihira improved the accuracy of the sine tables of Aryabhata I.

Arithmetic: He defined the algebraic properties of zero as well as of negative numbers.

Combinatorics: He was among the first mathematicians to discover a version of what is now known as the Pascal's triangle. He used it to calculate the binomial coefficients.

Optics: Among Varahamihira's contribution to physics is his statement that reflection is caused by the back-scattering of particles and refraction (the change of direction of a light ray as it moves from one medium into another) by the ability of the particles to penetrate inner spaces of the material, much like fluids that move through porous objects.

In Varahamihira's time, the commonest measures of rainfall were pala, adhaka, and drona: 50 palas made one adhaka and four adhakas constituted one drona. The rainfall was measured by means of a specially prepared round gauge with a diameter of one hasta or cubit (460 mm or 18 inches) and marked off in pala; when filled to capacity it indicated one adhaka of rainfall. It is believed that the Maurya and Gupta emperors introduced and popularized this system throughout the length and breadth of their extensive empires and consequently it became an all-Indian measurement. Many maxims and proverbs current amongst farmers and those close to the soil have their roots in the observations made by Indians millennia ago.

4.1.6.4. Conclusion

Varahamihira's fields of specialization ranged from medicine to surgery, mathematics, and meteorology. He had astonishing knowledge of a variety of subjects like hydrology, meteorology, astrology, astronomy, and seismology. His magnum opus is Brihatsamhita, which deals with all these subjects. He respected learning wherever it was found and was intimately acquainted with astrological literature of the Greeks to whom he made reference in his works. His other works included Pancha Siddhantika, Vivahapatala, Laghujataka, Yatra, possibly written in that order.

4.1.7. Nagarjuna

The flourishing of chemistry in India, especially alchemy, has an interesting phase during the period of tantra. The tantric cult in India was an admixture of alchemical processes on the one hand and grotesque rites on the other, centred on the worship of Siva and Parvati. We also have a class of tantras, which is an admixture of Buddhist and Saiva cults. Rasaratnakara ascribed to Nagarjuna belongs to this category. According to tantric cult, a man should preserve his body by means of mercury and medicaments. According to tantrics, mercury was produced by the creative conjunction of Siva and Parvati and mica was produced from Parvati. The combination of mercury and mica was believed to be destructive of death and poverty. Rasaratnakara of Nagarjuna contains descriptions of alchemical processes and preparations of mercurial compounds. Extraction of zinc, mercury and copper are described by him. He also elaborates on the preparation of crystalline red sulphide of mercury (swarnasindura or makaradhwaja) which is used as medicine for many ailments.

4.1.7.1. Biography

The alchemist Nagarjuna is well known for his treatise on alchemy titled Rasaratnakara, which was perhaps originally compiled around 7th or 8th Century CE. Nagarjuna was certainly a great scientist, who, for the first time, not only described cementation processes but also zinc production by a distillation technique. Arebian scholar Alberuni (10th century AD) mentioned about Nagarjuna, as native of the fort Daihak near Somnath, nearly a century before his own time and described as great adopt in Rasayana. If we shift Alberuni date about Nagarjuna a century or two backwords that is 8th century AD. Perhaps, Nagarjuna was born at Fort Daihak near the famous shrine of Somnath in Gujarat in 8th century A.D. He was a chemist, or an alchemist, as his efforts had been concentrated on transforming the base metals into gold. We are told that he had acquired such a reputation, due to his activities, that the people believed that Nagarjuna was in communion with gods and goddesses who had blessed him with the power of changing base metals into gold and the extracting of 'elixir of life'.

4.1.7.2. Works of Nagarjuna

Nagarjuna apparently reveled in the idea of his being looked upon as blessed by the gods. He himself added to this belief by writing his treatise, Rasaratnakara in the form of a dialogue between him and the gods. The treatise dealt with the preparation of rasa (liquids, mainly mercury). Nagarjuna has discussed various combinations of liquids in this volume. His treatise, the Rasaratnakara also gave a survey of the status of metallurgy and alchemy as it existed in India in those days. Methods for the extraction of metals like gold, silver, tin and copper from their ores and their purification were also mentioned, in Rasaratnakara. In his attempt to prepare the 'elixir of life' from mercury, Nagarjuna made use of animal and vegetable products, apart from minerals and alkalis. For the dissolution of diamonds, metals and pearls, he suggested the use of vegetable acids like sour gruel and juices of fruits and bark.

Some hsitrian opined that Nagarjuna was at a time a chemist, an alchemist, metallurgist and medicine man. His works are Rasaratnakara, Rashrudaya, Rasendramangal, Arogyamanjari, Kakshaputatantra, Yogasara, Yogasatak, Uttaratantra. Mohammed of Ghazni invaded India and is said to have destroyed some and taken some of the sciences manuscripts to the outside world. The Arabs learnt the transmutation of base metals to gold from Nagarjuna. They called it Al Kimia. Medieval Europeans learnt about it from the Arabs and called it Alchemy. In his treatise, he has also listed the apparatus that was used by earlier alchemists. The process of distillation, liquefaction, sublimation and roasting were also mentioned. Nagarjuna also discussed, in detail, the possibility of transmutation of base metals into gold. But although he could not produce gold, these techniques did yield metals with gold like yellowish brilliance. Till today these methods are being used to manufacture imitation jewelry.

Nagarjuna has also discussed methods for the preparation of mercury like calamine. Later Nagarjuna seems to have turned towards organic chemistry and medicine. He has written a text called Uttaratantra which is supposed to be a supplement to an earlier text the Shusrutasamahita which is said to have been written by Shusruta long before him. Nagarjuna's Uttaratantra deals mainly with the preparation of medicinal drugs. He also wrote four Ayurvedic treatises named Arogyamanjari Kakshaputatantra, Yogasara and Yogasatak.

4.1.7.3. Contribution

An alchemist he knew the art of transmuting base metals to look like gold. This method is today being used to make imitation jewellery, Preparation of mercury, Extraction of metals like gold, silver, tin and copper from the ore, Dissolution of diamonds, metals and pearls, Process of distillation, liquefication, sublimation and roasting, Combinations of liquids, Preparation of medicinal drugs. As Alchemy, as is well known, has a twofold objective: (i) the preparation of an elixir of life and (ii) the production of the philosophers' stone for the transmutation of base metals into gold. Tantric treatises, both Brahmanic and Buddhistic, abound in recipes for such transmutation of base metals, particularly of mercury into gold. The Rasa-ratnakara, attributed to the Nagarjuna, contains descriptions of alchemical processes and preparations of many mercurial compounds. It gives an account of many chemical processes like the extraction of zinc, mercury, and copper, and the preparation of crystalline red sulphide of mercury (svarnasindura or makaradhvaja). This medicament is still used as a panacea for many ailments by physicians in India following the indigenous system of medicine. The treatise also describes more than two dozen varieties of apparatuses (yaniras) for carrying out various physico-chemical processes like distillation, sublimation, extraction, calcination, digestion, evaporation, filtration, fumigation, fusion, pulverization, heating by steam and by sand, and the preparation of many metallic compounds.

Thus Nagarjuna seems to have been a copious writer. As he lived in the 8^{th} Century A.D his works incorporate the ideas of earlier chemists and physicians. Only a few decades after Nagarjuna, India was invaded by the Mohammedans: Mahmud of Ghazni had raided and plundered Nagarjuna's hometown of Somnath in 1020 A.D. It is possible that Nagarjuna's texts fell into the hands of the invaders. While the invaders ruthlessly destroyed the architectural achievements of this country and imposed their despotic rule, they also transmitted Indian sciences to the outside world. Alongwith Mahmud of Ghazni came scholars like Al Beruni who studied Indian texts and translated them into Arabic. Many Indian ideas of medicine were incorporated into the Unani system of medicine of the Arabs. Nagarjuna's works could not have escaped their attention. It is possible that the technique of alchemy was borrowed by the Arabs from India. In the ancient world there is no reference to alchemy. We first hear of it in the medieaval Europe. The homeland of the Arabs is not rich in metals, thus alchemy and the smelting of metals could not have been indigenous to the Arabs.

Thus the Arabs seem to have borrowed the technique of transforming base metals info gold-like metals from India. The Arabs called the technique Al Kimia which according to the Oxford Dictionary literally means the 'transformation of metals'. Al means 'The' and Khimia which is derived from the Greek term Khemia means 'to transmute metals'. But westerners did not appear to have had the knowledge of the technique of alchemy. This is borne out by the fact that the term Alchemy which the westerners use for describing this technique was borrowed from the Arabs. The word Achemy is obviously a corruption of the term Al Kimia which the Arabs gave to the technique of converting base metals into gold like substances which they culled out from Indian texts on the subject.

4.1.8. Conclusion

Science and Mathematics were highly developed during the ancient period in India. Ancient Indians contributed immensely to the knowledge in Mathematics as well as various branches of Science. Scientist flourished in India and cultivated astronomy and mathematics and took both the subject to their height. Baudhayan was the first one ever to arrive at several concepts in Mathematics, which were later rediscovered by the western world. The value of pi was first calculated by him. What is known as Pythagoras theorem today is already found in Baudhayan's Sulva Sutra, which was written several years before the age of Pythagoras. Aryabhatta was a fifth century mathematician, astronomer, astrologer and physicist. He was a pioneer in the field of mathematics. Aryabhatta showed that zero was not a numeral only but also a symbol and a concept. Discovery of zero enabled Aryabhatta to find out the exact distance between the earth and the moon. He also gave a scientific explanation for solar and lunar eclipse clarifying that the eclipse were not because of Rahhu and/or Ketu. In 7th century, Brahmgupta took mathematics to heights far beyond others. In his methods of multiplication, he used place value in almost the same way as it is used today. Bhaskaracharya was the leading light of 12th Century. He is famous for his book Siddanta Shiromani. Bhaskara introduced Chakrawal Method or the Cyclic Method to solve algebraic equations. Varahamihira was another well known scientist of the ancient period in India. He lived in the Gupta period. Varahamihira made great contributions in the fields of hydrology, geology and ecology. Nagarjuna was a eighth century alchemist. In his treaties *Rasaratnakara*, he has discussed methods for the extraction of metals like gold, silver, tin and copper.

4.1.9. Summary

- *Baudhayan was the first one ever to arrive at several concepts in Mathematics, which were later rediscovered by the western world.*
- *The value of pi was first calculated by him. As you know, pi is useful in calculating the area and circumference of a circle. What is known as Pythagoras theorem today is already found in Baudhayan's Sulva Sutra, which was written several years before the age of Pythagoras.*
- *Aryabhatta was a fifth century mathematician, astronomer, astrologer and physicist. He was a pioneer in the field of mathematics. At the age of 23, he wrote Aryabhattiya, which is a summary of mathematics of his time.*
- *Aryabhatta showed that zero was not a numeral only but also a symbol and a concept. Discovery of zero enabled Aryabhatta to find out the exact distance between the earth and the moon. The discovery of zero also opened up a new dimension of negative numerals.*
- *He also gave a scientific explanation for solar and lunar eclipse clarifying that the eclipse were not because ofRahhu and/or Ketu or some other rakshasa (demon,).*
- *In 7th century, Brahmgupta took mathematics to heights far beyond others. In his methods of multiplication, he used place value in almost the same way as it is used today. He introduced negative numbers and operations on zero into mathematics. He wrote Brahm Sputa Siddantika through which the Arabs came to know our mathematical system.*

- *Bhaskaracharya was the leading light of 12th Century. He is famous for his book Siddanta Shiromani. It is divided into four sections: Lilavati (Arithmetic), Beejaganit (Algebra), Goladhyaya (Sphere) and Grahaganit (mathematics of planets).*
- *Bhaskara introduced Chakrawal Method or the Cyclic Method to solve algebraic equations. This method was rediscovered six centuries later by European mathematicians, who called it inverse cycle. In the nineteenth century, an English man, James Taylor, translated Lilavati and made this great work known to the world.*
- *Varahamihira was another well known scientist of the ancient period in India. He lived in the Gupta period. Varahamihira made great contributions in the fields of hydrology, geology and ecology. He was one of the first scientists to claim that termites and plants could be the indicators of the presence of underground water.*
- *Varahamihira was one of the nine gems, who were scholars, in the court of Vikramaditya. Varahamihira's predictions were so accurate that king Vikramaditya gave him the title of 'Varaha'.*
- *Another field where Varahamihira's contribution is worth mentioning is Jyotish or Astrology.*
- *Nagarjuna was a eighth century scientist. The main aim of his experiments was to transform base elements into gold, like the alchemists in the western world. Even though he was not successful in his goal, he succeeded in making an element with gold-like shine. Till date, this technology is used in making imitation jewelry. In his treatise, Rasaratnakara, he has discussed methods for the extraction of metals like gold, silver, tin and copper.*

4.1.10. Exercise

- Discuss the career and contribution of Baudhayana in the ancient India mathematics.
- Assess the works of Aryabhatta in ancient Indian astronomy.
- Enumerate the achievements of Varahamihira in the sphere of ancient Indian astronomy.
- Examine the role played by Bhaskaracharya for the development of astronomy in ancient India.
- Write an essay on the contribution of Nagarjuna in the sphere of chemistry in ancient India.

4.1.11. Further Readings

- Peter Della Santina, *Causality and Emptiness: The Wisdom of Nagarjuna*, Singapore: Buddha Dharma Education Association, 2002.
- Siderits, Mark and Shōryū Katsura,: *Nagarjuna's Middle Way*. Mūlamadhyamakakārikā, Boston: Wisdom Publications, 2013.
- Westerhoff, Jan, *Nagarjuna's Madhyamaka. A Philosophical Introduction*, Oxford: Oxford University Press, 2009.
- Sarma, K. M. K., 'Varahamihira,' in Scientists, 73-82. Publications Division, Government of India, New Delhi, 1976.
- Cooke, Roger., The History of Mathematics: A Brief Course. Wiley-Interscience, 1997.
- Clark, Walter Eugene., The Aryabhayiya of Aryabhaya: An Ancient Indian Work on Mathematics and Astronomy. University of Chicago Press; 1930, reprint: Kessinger Publishing, 2006.
- Kak, Subhash C., 'Birth and Early Development of Indian Astronomy'. In Selin, Helaine, ed. Astronomy Across Cultures: The History of Non-Western Astronomy. Boston: Kluwer, 2000.
- Shukla, Kripa Shankar. Aryabhata: Indian Mathematician and Astronomer. New Delhi: Indian National Science Academy, 1976.
- George Gheverghese Joseph. The Crest of the Peacock: Non-European Roots of Mathematics, 2nd Edition. Penguin Books, 2000.
- S. Balachandra Rao, Indian Mathematics and Astronomy: Some Landmarks. Jnana Deep Publications, Bangalore, 1998.

*****

Unit-4
Chapter-II
MEDICAL SCIENTIST OF ANCIENT INDIA (AYURVEDA & YOGA): Susruta, Charak & Patanjali.

Structure

4.2.0. Objectives

This chapter deals with the medical scientist of ancient India particularly Ayurveda and Yoga. After reading this chapter, you will be able to;

- *trace the career and contribution of Susruta to Ayurveda;*
- *describe the life and contribution of Charak in the sphere of ancient Indian medical science;*
- *be acquainted with the concept of Yoga and contribution of Patanjali to this form of medical science I ancient India.*
- *trace the Impact of ancient Indian Medical sciences in common people.*

4.2.1. Introduction

Scientific knowledge was in a highly advanced stage in ancient India. In keeping with the times, Medical Science was also highly developed. Ayurveda is the indigenous system of medicine that was developed in Ancient India. This ancient Indian system of medicine not only helps in treatment of diseases but also in finding the causes and symptoms of diseases. It is a guide for the healthy as well as the sick. While treating a disease with the help of herbal medicines, it aims at removing the cause of disease by striking at the roots. The main aim of ayurveda has been health and longevity. Susruta, Charak, Madhava, Vagbhatta and Jeevak were noted ayurvedic practitioners. Besides the Ayurveda, the science of Yoga was developed in ancient India as an allied science of Ayurveda for healing without medicine at the physical and mental level. Like all other sciences, it has its roots in the Vedas. The credit of systematically presenting this great science goes to Patanjali. This chapter throw light on the ancient luminaries of India related to Ayurveda and Yoga.

4.2.2. Susruta

Ayurveda is described as science of life and it was recalled by Brahma as mentioned in Ayurvedic treatises. Brahma transformed his noble knowledge to Prajapati or Daksha, later Daksha passed his legacy to Ashwins and Indra received knowledge from Aswins. As per Sushruta opinion, Indra taught Ayurveda to Dhanvantari, the surgeon of gods embodied as king Divodasa of Banaras (Kashiraja). Divodasa then transmitted medical knowledge with special reference to surgery to the wise men like Sushruta and others who approached him as pupils, out of sympathy for the suffering humanity and also in order to prolong their own life. Sushruta composed 'Sushruta-Samhita' on the basis of percepts of his teacher Kashiraja Divodasa Dhanvantari which is considered the best book for Shareera (knowledge related to Human Anatomy and Physiology). Sushruta is equally famous with Charaka, and he is named with Atreya and Harita in the Bower Manuscript. The Mahabharata represents him to be a son of Vishvamitra. Nagarjuna is credited with having worked over his text. Moreover, like Charaka, he won fame beyond India and he was renowned both in Cambodia in the east and Arabia in the west around 9th and 10th centuries. We have also a revised text of Sushruta-Samhita prepared by Chandrata on the basis of the commentary of Jajjata. Charaka-Samhita, Sushruta-Samhita and Samhitas of Vagbhata are considered as the main Samhitas of Kritayuga, Dvaparayuga and Kaliyuga respectively.

In Kshemakutuhala text, it is well versed that a Vaidya who has listened many more text books but not listened the Sushruta-Samhita is devoid of actual benefits and if studied many other books but not the Charaka-Samhita gets defame or criticism among Vaidyas who have studied both the Samhitas. Vagbhata says that if the texts written by seers and sages get recognition in society then except Charaka-Samhita and Sushruta-Samhita why BhelaSamhita etc. are not studied. All these references prove the gravity of Sushruta-Samhita, Charaka-Samhita and Samhitas of Vagbhata in the field of Ayurveda. SushrutaSamhita is one of the most authentic texts of Ayurveda begins with a Sutrasthana, which deals with general questions and makes out that Sushruta's teacher was king Divodasa of Benares, an incarnation of Dhanvantari, physician of the gods. Nidanasthana deals with diagnosis (Nidan-Panchaka of diseases) in detail; Sharirasthana covers anatomy and embryology; Chikitsasthana contains therapeutics, Rasayana and Vajikarana; Kalpasthana deals with toxicology; and the Uttaratantra covers diseases of urdhwanga (upper body parts), Balagraha, Kayachikitsa and Bhutavidya mainly which is clearly a later edition, supplements the work. The view of Hoernle that even this later book is as old as Charaka and Bhela-Samhita appears to be quite untenable, for it rests on his erroneous view that the anatomical view of Sushruta were known to the author of the Shatapatha Brahmana,a view which has been disproved. It is of interest to note the high standard demanded from a doctor by Sushruta; the introduction of the student is based on the formal initiation of a youth as a member of twice-born; he is made to circum-ambulate a fire, and a number of instructions are given to him including purity of body and life; he should wear a red garment-an idea with many parallels; his hair and nails are to be cut short; he is to treat as if they were his kith and kin, holy men, friends, neighbors, the widow and the orphan, the poor and travelers, but to deny his skills to hunters, bird-catchers, out-castes, and sinners.

Sushruta is mainly concerned with surgery and elaborates many surgical procedures like Karnapali-sandhana, NasaSandhana and Aushtha-Sandhana, Vranopakrama, treatment of Asthibhagna and Sandhibhagna, Siravedha and the surgical treatment of different diseases which is indicative of his excellent surgical skills. About 900 A.D, Sushruta was cited in an Arabic translation of the famous Arabian physician Razi (Rhazes) in such a way that one feels that this translation could well have been based on Sushruta-Samhita. The present condition of the whole Sushruta is indeed borne out by the commentaries, especially the Bhanumati of Chakradatta (11 th cent.) and the Nibandhasamgraha of Dalhana (12th cent.). Jejjata is usually considered as their predecessor. On the basis of his commentary Chandrata, son of Tisata undertook a revision (Pathashuddhi) of the text of Sushruta. According to Hoernle many original readings can still be restored from Bhanumati. On the base of Sutrasthana 1st chapter 39th Shloka and Sutrasthana 4th chapter 5th Shloka and one can draw the conclusion that originally there were 120 Adhyayas in five sthanas and Uttaratantra was supplemented in later addition.

Sushruta, such a great legendary in the field of Ayurveda especially in Shalya-Tantra has not given his proper introduction anywhere in text which creates curiosity among historians and ayurvedists. This article deals with the historical study of such a great personality and his special contribution in the field of Ayurveda.

4.2.2.1. Biography

The word Sushruta means well-heard or versed in the Vedas. Sushruta is the author of a Sushruta Samhita, whose work, together with that of Charaka, is regarded as the oldest medical authority, and held in great esteem in India till today. Personality of Sushruta is also debatable like Charaka as there are references of being two Sushrutas viz.-Vriddha Sushruta and Sushruta. References of Vriddha Sushruta are available in the NibandhaSamgraha commentary of Sushruta-Samhita written by Dalhana, Sarvangasundari Vyakhya of Ashtanga-Hridaya, Madhukosha Vyakhya of Madhav-Nidan, Bhavprakash etc. but these references are not available in presently available edition of Sushruta-Samhita. These references prove the existence of Vriddha Sushruta. It is also assumed that Vriddha Sushruta wrote the original text and Sushruta redacted it. Acharya P.V. Sharma in his book on history named "Ayurveda ka Vaigyanika Itihasa" discussed about the Vriddha Sushruta and Sushruta and accepts that such type of situation is with many other streams also. He discussed about the development of Sushruta-Samhita in four steps i.e. Vriddha Sushruta, Sushruta, Nagarjuna and Chandrata. The introduction of Kashyapa-Samhita disagrees with the view of VriddhaSushruta as there is no reference of Vriddha-Sushruta in the list of predecessor seers and sages, Mahabharata also quotes the name of Sushruta as a son of Vishvamitra, Mahabhashyakara, Nagarjuna, Vagbhata and Navanitakakara also quote the Sushruta not the Vriddha Sushruta, unfamiliarity of Vriddha-Sushruta as a surgeon etc. are the facts against the acceptance of VriddhaSushruta. Sushruta does not mention about Vriddha Sushruta anywhere in his text, so it is difficult to accept the Vriddha Sushruta. As the name Sushruta appears in many ancient treatises, each one of them giving different information creates difference of opinion.

Sushruta-Samhita mentions that Sushruta was the son of sage Vishvamitra. He along with Aupadhenava, Vaitarana, Aurabhra, Paushkalavata, Karavirya, Gopurarakshita and others approached Divodasa, The Kashiraja (king of Kashi) to teach them Ayurveda especially Shalya-Tantra (surgery). Mahabharata mentions Sushruta as one of the sons of sage Vishvamitra, the teacher of Rama and

Lakshmana, princes of Ayodhya, but it does not mention about Sushruta as a learner of Ayurveda from Divodasa, the king of kashi. Bhavaprakasha mentions that Vishvamitra etc. seers and sages knew through their divine vision that Kashiraja Divodasa is an incarnation of lord Dhanvantari, so Vishvamitra told his son Sushruta to go Varanasi and get the education of Ayurveda from Kashiraja Divodasa Dhanvantari. Garuda-Purana also mentions Sushruta as the son of Vishvamitra. Shalihotra-Samhita, a treatise on the science of medicine of the horses (Ashvayurveda) mentions Sushruta as the son of sage Shalihotra who learnt that science from his father. Mitrajita, Gandhara, Garga and others were his classmates. Agni-Purana states that Sushruta learnt both human medicine (Narayurveda) and medicine of horses (Ashvayurveda) from Dhanvantari Divodasa, the king of Kashi24. On the base of all the informations and references, majority of scholars are of the view that Sushruta, son of Vishvamitra, was the disciple of Divodasa, king of Kashi. But here is again difficult to identify that which Vishvamitra was the father of Sushruta as many sages having this name are available in the history e.g. Vishvamitra as a seer in Rigveda of many hymns, Vishvamitra as the son of king Gadhi, ruler of Kanyakubja and teacher of Rama and Lakshmana, as an author of a treatise on Ayurveda, as an author of Dhanurveda, as an author of Dharmashastra etc. Out of these, the view that Vishvamitra of the Ramayana is the father of Sushruta has been generally accepted. Sushruta, the son of sage Shalihotra may be the different authority, as no more description on Ashvayurveda is available in Sushruta-Samhita.

4.2.2.2. Date of Sushruta

Historians accept the ambiguity in the exact period of Sushruta. Hass accept Sushruta in 12th century, Jones Wilson in 9-10th century, Macdonal in 4th Cent.B.C, Hoernle accept 6 century before Vikrama Samvata, Hessler and Shriyut Girindranath Mukhopadhyaya accept 1000 B.C. On the basis of all these views SushrutaSamhita, Part-1 may be 2600 years old26. Acharya P.V. Sharma considers two Sushruta i.e. Vriddha Sushruta and Sushruta. He accepts Vriddha Sushruta in the time period of Kashiraja Divodasa Dhanvantari and it is 1000-1500 B.C. Sushruta, the redactor of main text can be placed in the 2nd century A.D on the basis of many supportive references such as - Hora word is used in Sushruta Samhita which is derived from Horus, the Greek word.

The good contact with Greek people took place in 4^{th} Cent.B.C. So the date of second Sushruta will be after 4^{th} Cent.B.C. Sushruta mentions Yuktaseniya adhyaya, Dundubhiswaniya agada and many more topics related to king which shows his relation with any king possibly Satavahana Samrata Gautamiputra Shatakarni who is considered in between the 2nd – 3 rd Cent.A.D. Vasudeva Dharma is abundantly followed in Sushruta-Samhita which grew in 1 st to 4th Cent.A.D. Shashthi-puja which was in vogue in Gupta period is not mentioned in Sushruta-Samhita.Two type of classification of Ritu (season) is available in Sushruta-Samhita, Ekendranath Gosh, on the base of mathematics, stated 1500 years difference in between the two type of classification. So if we consider the first classification of Kashiraja Divodasa Dhanvantari, then second classification may be linked with Pratisamsakarta Sushruta. On the basis of all these references, the time period of second Sushruta stands near about 2nd century A.D. If we accept one Sushruta as per the opinion of Nepal Rajaguru Pt.Hemraj Sharma,the time period of Sushruta will be the same as is accepted for Kashiraja Divodasa Dhanvantari and that is 1500-1000 years B.C.

4.2.2.3. Place of Sushruta

Sushruta has not mentioned his birth place any where, but he quoted many places related to south India such asmountains, source places to collect Jalauka i.e. leech and used Dakshinapatha word in different context for south which show his relation some how with southern part of India. In Etareya Brahmana, the origin of the Andhrapradesha is considered by Vishvamitra. Sushruta is considered as a son of Vishvamitra. Scholars from southern part namely Ugradityacharya etc. followed Sushruta mostly28. All these references suggest that he may be from southern part of the India.

4.2.2.4. Contribution of Sushruta

Charaka and Sushruta are considered the two exemplary personalities in the field of Ayurveda. Vagbhata clearly accepted the indebtness to both the Charaka and Sushruta. In medieval period;

Naishadhiyacharita also quoted both the authorities. In the inscriptions of king Yashovarman (9th-10th Cent.A.D.), Sushruta is quoted respectfully. Arabic physician Rhazes (9thcent.A.D.) also mentioned Sushruta in his writings. Sanaka, the textbook of Toxicology is based on the Kalpasthana of SushrutaSamhita. The Navanitakam, the old book of medicine quotes Sushruta but not the Charaka which shows the name and fame of Sushruta and it seems that SushrutaSamhita was more popular at that time than CharakaSamhita29. If we accept Vriddha Sushruta and Sushruta then the Aupanishadika description goes in credit of Vriddha Sushruta and Pauranika and Pre-Guptakalina description can be credited to Sushruta. But it will be better to assume Sushruta as a single personality as sufficient references are not available in the original text of Sushruta-Samhita about Vriddha Sushruta. Sushruta elaborates the other specialties of medicine but mainly the Shalya-Tantra (surgery) as in the beginning of Samhita he quotes "Shalyagyanam samantatah" means surgical knowledge is mentioned everywhere in his text. The specific contributions of Sushruta by his text are teaching and learning methods, Yogya, dissection of cadaver at the macro level, exclusive description of Yantra-Shastras, shashti upakramas of Vrana (sixty types of treatment procedures of wound), Kshara-karma, Agni-karma, Jalauka-avacharan, detail description of Siravedha (venepuncture), Sandhana-Shalyakarma (plastic surgery) such as- Nasa-sandhana, Karnapali-Sandhana etc.,discussion of Emergency conditions likeUshnavatatapadagdha,Shitavarshanilahata,Indravajradagd ha,Dhumopahata (burns), Udakapurnodara (drowning), Bahurajjulatapasha (hanging and strangulation), description of Marma, differentiation of Shira, Dhamani and Srotas, discussion about Pitta and Agni, five types of Pitta Dosha, Shatkriyakala, ideal definition of healthy person, description of aupasargika rogas (infectious diseases) like-Kushtha, Jwara, Shosha etc., detail informations of Visha-Vidya (toxicology), first time mentioning of Phenashma, Haritala as Dhatu-Visha, purification or neutralization of aerobic toxins by Dundubhiswaniya, initiation of military medicine in the form of Yuktaseniya adhyaya,various pharmaceutical preparations such as- Putapaka, Ayaskriti, Asava-Arishta, Churnakriya etc., properties of medicines according to their place of origin, Panchapanchamula gana etc. Sushruta's contributions are linked with different specialties of Ayurveda which shows his great wisdom and devotion towards medicine and ultimately towards the service of suffering humanity.

4.2.2.5. Conclusion

Sushruta and Sushruta-Samhita are two famous names in the history of Ayurveda. Credit of Sushruta-Samhita goes to Kashiraja Divodasa Dhanvantari, Sushruta, Nagarjuna, and Chandrata who are the preceptor, composer, redactor and amendor respectively. The extant Sushruta-Samhita is the comprehensive dealing with all the eight specialties of Ayurveda with greater portion of Shalya-Tantra. Sushruta, who might be a son of Vishvamitra, composed it in 1500- 1000 year B.C. on the base of perceptions of his teacher and later on redacted by Nagarjuna who possibly added the Uttara-Tantra also. Chandrata amended it in 10th Cent.A.D. on the basis of available commentary of Jejjata. Because of catering all the needs and requirements of medical sectors, many commentators wrote commentaries on it out of which Nibandha-Samgraha commentary by Dalhana (12th Cent.A.D.) is fully available and accepted by physicians due to its unique explanations of the subject. Sushruta has not mentioned his detail identity in his classic, so it is quite difficult to comment upon it but he has contributed a lot in the field of Ayurveda especially in Sharira and Shalya-Tantra which is the shining and everlasting identity. Looking toward his contributions made in Ayurveda, it becomes clear that he is the great Surgeon and visionary in the field of Ayurveda.

4.2.3. Charaka

The Charaka-Samhita, as available in its present form containing eight sthanas or sections such as-Sutrasthana, Nidanasthana, Vimanasthana, Shareerasthana, Indriyasthana, Chikitsasthana, Kalpasthana and Siddhisthana, is originally the work of Agnivesha who composed his Tantra on the base of the teaching of his teacher Punarvasu Atreya. The second and prominent stratum in the Charaka-Samhita is that of Charaka on whose name the book is known. The term 'Charaka' is derived from the root 'car' means to move about.

Charaka has propagated his knowledge and gave relief to the patients by moving from place to place. He stands after Agnivesha in the period when Buddhism was prevalent side by side with Brahmanic culture in which worship of different deities like Shiva, Vishnu and Kartikeya was in practice. Charaka has also prescribed oblations to Dhanvantari who emerged as medicine-god in Puranas and was worshipped as god at that time. After a lapse of time, some of its contents were lost which were reconstituted and restored by Dridhabala. It is not difficult to identify the Subject matter added by Dridhabala as he has clearly mentioned about it in the last chapter of Charaka-Samhita that he has added 17 chapters of Chikitsasthana and whole the Kalpasthana and the Siddhisthana in Charaka-Samhita. The compendium of Charaka is well accepted up to the date today by medical fraternity because of it's gravity in the form of valid fundamental principles, psychosomatic approach, scientific ideas and multidimensional approach to treat the patient, but who is Charaka? It is not clear even today. So let us discuss in the depth of history about such a great legendary and visionary.

4.2.3.1. About Charaka

Charaka has contributed a lot in the field of medical science but no where introduced himself which creates problem in deciding the actual personality. Many scholars of history and other streams have tried their best to establish the identity but even today, it is doubtful that whether this Charaka was a person or a community. Few of the important views which are available exclusively in almost all the history books are as follows-Charaka is said to have been an incarnation of Shesha–the serpentgod with a thousands heads-who is supposed to be the depositary of all sciences, especially of medicine. In Bhavaprakasha Charaka is introduced as the son of Vishuddha and incarnation of serpent god. There is a fine legend about it mentioned in Bhavaprakasha, a 16th century work. Shesha or serpent god is adored as the embodiment of the knowledge of the Vedas including Ayurveda. Once he himself came to the earth to enquire about the welfare of the living beings here and found them in a miserable state of health due to the spread of diseases. Being very much moved by the pathetic scene, he himself took birth in a family of a learned sage Vishuddha. He redacted Agnivesha's work named "Agnivesha-Tantra" and renamed it as "CharakaSamhita".

According to current tradition, Charaka is identified with Patanjali probably on two reasons- one, both are regarded as incarnation of Sheshanaga and the other, both are concerned with purification of body, speech and mind. Patanjali is said to purify body, speech and mind by the precepts of the Charaka Samhita, the Mahabhashya and the Yogasutra. In the 'Charaka Panjika' commentary of Charaka-Samhita by Swamikumar, Charaka is said to purify speech, mind and body by the percepts of the Vyakarana Mahabhasya, Yogasutra and Charaka Samhita. Though it would be interesting to make a comparative study of these three texts, it is difficult to prove these texts as works of a single author (Patanjali) because of heavier points against it. Patanjali name is not mentioned in whole Charaka-Samhita anywhere. There is no similarity in the pattern of mentioning the subject matter and different places mentioned in Mahabhashya are absent in CharakaSamhita. The reason behind bringing these three texts together may be the similar role in the purification of body, speech and mind respectively. Reference of "Patanjal-Vartika" on Charaka-Samhita is available in Patanjali Charita written by Ramachandra Dikshita. It also creates confusion that whether Charaka and Patanjali are single authority or two different authorities.

In Vedic times, a branch of Krishna Yajurveda was known as Charaka. Charakas were disciples of Vaishampayana who himself was known as Charaka. Charaka might be one of the followers of this section. The branch of Atharvaveda named Vaidyacharana may be related to medicine and Charaka may be a physician belonging to that section who roamed from place to place offering medical services to the people. Sylvan Levi on the basis of Chinese translation of Buddhist text (Samyuktaratnapitakasutra) accepted that Charaka was attached as a physician to King Kanishka. Julius Jolly, The writer of Indian Medicine writes in his text "Thus chronologically very little can be said against the identification of Charaka with Kanishka's courtphysician". Most of the scholars are against with this idea as Charaka was physician of roaming nature and how he could have been bound to a court of a king Kanishka. In ancient time, the famous physicians were named Charaka, so there may be another Charaka as a physician in the court of Kanishka but not the Charaka who redacted the Agnivesha-Tantra.

It is also considered by the scholars that the actual name of Charaka was Kapishthala. Charaka was a resident of Kapisthala village in Panchanada (Punjab) which is situated between Iravati and Chandrabhaga rivers. It is not evidence based because Kapisthala is one of the twelve branches of Charaka out of 86 branches of Yajurveda. Kapishthala was a sage but there is no reference of his relation with Charaka-Samhita or Ayurveda. Apart from this the word Charaka is used in different literature in the sense of messenger or Ayurvedic text. Charaka word is used in the sense of ranger also in some of the texts. Gradually Charaka was established as sect comprising of wandering medicants who practiced medicine and mentioned along with Shramana, Tirthika and Parivrajaka (roaming ascetics).

Alberuni (11 th Cent.A.D.), a contemporary of Mahamuda Gajanavi and one of the poets of his court consider Agnivesha and Charaka as a single authority in his writing, but this view is not acceptable because in each and every colophon of the chapters of Charaka-Samhita (Agnivesha krite Tantre Charaka pratisanskrite), reveals clearly that Agnivesha was the composer of original text and Charaka was the redactor of the same text and separate personality. After discussing all the views, it is clear that it is quite difficult to introduce the Charaka exactly, yet on the basis of the opinion of most of the scholars, it can be assumed that he may be one of the followers of the branch of Krishna Yajurveda.

4.2.3.2. Time of Charaka

External evidences: Vagbhata (6th century A.D.) has explicitly quoted Charaka. Yagyavalkya Smriti (3 rd Cent. A.D.) has taken many things from the Charaka-Samhita such as the concept of Shaddhatvatmaka Purusha, the signs of Paramatman, monthly development of foetus, six layers of skin, 360 bones, five Gyanendriyas, five Karmendriyas, ubhayatmaka Manas etc. Navanitaka (2nd Cent.A.D.) has quoted many formulae from Charaka-Samhita though mentioning the name of Agnivesha and not of Charaka. Ashvaghosha, the contemporary of Kanishka (1 st Cent. A.D.) has also borrowed many things from Charaka Samhita though he has mentioned Atreya and not Charaka. The CharakaSamhita was translated into Pahlavi language in the early centuries of the Christian era, hence the original text must be quite earlier. Milindpanha (2nd Cent.B.C.) has many things similar to those in the Charaka-Samhita. For instance, the vedana which has got important place in Charaka Samhita has been described in detail in this text.

The perception of rasa in contact with gustatory sense organ has been mentioned as the method suggested by Charaka. All this indicates antecedence of Charaka. Although Panini (7th Cent. B.C.) mentioned Charaka but it is in the sense of one of the Yajurvedic tradition and not as the author of Charaka Samhita. Hence Charaka may be placed after Panini (7th Cent. B.C.) and before Milindpanha (2nd Cent.B.C.) e.g. about 3 rd-2nd Cent. B.C.23.

Internal Evidences: Philosophical background- Philosophical material available in Charaka-Samhita indicates its existence before 2nd Cent.A.D. Samkhya philosophy mentioned in Charaka Samhita is the earlier than Samkhya-karika (2^{nd} Cent.A.D). Names of three types of Anumana are not mentioned in Charaka Samhita which are found in Nyayasutra (2nd Cent.A.D) Religious condition- There is number of references of Puranas which shows their dominance at that time. The Pauranika legend with regard to the origin of certain diseases like- Jwara, Rajayakshma etc. confirm this situation. Similarly sadvrittas mentioned in CharakaSamhita are based on Dharmasutras. Political condition-At many places king, Ishvara and Mahajana (rajamatramanyam va) are mentioned. It is also mentioned in Charaka Samhita that quackery becomes prevalent due to slackness of government and epidemics spreads due to negligence of the state. This shows the weak administration of the era. Charaka Samhita took its shape when Buddhism was developing, Brahmanism was having upper hand. The religious literature was being given concrete shape in the form of Puranas and Sutras and religious sacrifices were commonly performed. Such condition is met with during the period of Maurya-Sungas (3-2nd Cent. B.C.).The description of hospital in Charaka-Samhita also confirms this view because number of dispensaries and hospitals were established during the tenure of King Ashoka. Shakas are mentioned by Patanjali and Vagbhata but not by Charaka, which shows that he was prior to Patanjali and Vagbhata. Thus on the basis of all the evidences, the time period of Charaka may be decided as 3rd or earlier 2nd cent. B.C. at the juncture of Maurya-Shunga periods.

4.2.3.3. Place of Charaka

Charaka has nowhere mentioned his birth place or place of origin. There is mention of mainly north-west regions of India in Charaka-Samhita, such as- Himalaya, Panchala Kshetra, Kailasha, and Panchanadapura etc. On the basis of this fact some of the scholars assume that he may be from north-west region of the India. Because there is no reference of birth place in whole text, so every Historian is silent about this fact. Some believe him to have been born at Benares 320 years B.C. He was the greatest physician of his day, and his Charaka Samhita is still held to be a standard work on Medicine.

4.2.3.4. Contribution Of Charaka

It is very interesting to discuss that no other Samhita is renamed after redaction except Charaka Samhita. Again it is specific to comment upon that after the redaction done by Dridhabala, nomenclature was not changed. It shows that Charaka not only retouch or redact but thoroughly revised the Agnivesha Tantra, elaborated according to need on the basis of prevailing authentic knowledge and gave it new shape and wrote his own treatise. Contribution of Charaka can be decided on the basis of comparison with Bhela Samhita as Bhela was one of the colleagues of Agnivesha and composed treatises on the basis of their teacher's perceptions. So it can be supposed that Agnivesha Tantra may be more or less similar to Bhela-Samhita in size and contents. All the additions and improvements made particularly logical, development of basic concepts and philosophical discourses in the light of Buddhism etc. may go to Charaka's credit. The description of hospital also seems to be from him. The detailed classifications of drugs and pharmacological concepts also owe to him. Such descriptions are lacking in Bhela Samhita. Dr. Mahamahopadhyaya Satish ChandraVaidyabhushana in his history of Indian logic supposes without adducing any reason that the Charaka-Samhita gives a summary of the principal doctrines of Anvikshiki possibly as propounded by Medhatithi Gautam. He further says that the doctrines of Anvikshiki evidently did not constitute a part of the original Ayurveda of Punarvasu Atreya, and that these doctrines seems to have been incorporated into Charaka-Samhita by it's redactor Charaka in whose time they were widely known and studied. On the basis of this statement it seems that Panchavayava, Vadamargas and Sambhasha Vidhi etc are included by Charaka. Swabhavoparamavada may be added by Charaka as Boddha dharma came into existence after Agnivesha and before Charaka. Description of hospital mentioned in 15th chapter of Sutrasthana of Charaka Samhita may be the idea of Charaka because such types of hospitals were being established at that time by Maurya emperor.

Ayurvedavatarana or transmission of Ayurveda mentioned in 1st chapter of Charaka Samhita Sutrasthana may be added by Charaka. Ashtanga division of Ayurveda mentioned in 30th chapter of Sutrasthana of Charaka Samhita also seems added by Charaka on the basis of available edition of Sushruta with minor changes in the names. In other Samhitas, Ashtanga division of Ayurveda is at the very beginning. Varna Vyavastha and Ashrama vyavastha is developed during the period of Purana and Smriti granthas. Charaka stands near that period so may be Charaka included this Varna and Ashrama Vyavastha in the Charaka-Samhita.

4.2.3.5. Conclusion

After the historical study of Charaka, it is quite clear that this great personality in the field of Hindu medicine has not given his introduction anywhere which shows that he was fully concentrate on work and not worried for the name and fame. According to the view of most of the scholars, he may be one of the followers of the branch of Krishna Yajurveda who exists in between the period of 3 rd-2nd Cent.B.C. Probably he was from north-west region of the country. The great contribution in the field of Ayurvedic medicine in the form of Charaka Samhita introduces his greatness. He has contributed a lot in the area of medicine specially the fundamental doctrines and unique approaches of treatment which differ him from other authorities of the same field and perhaps it is the cause why Charaka Samhita is considered as the best book for medicine. Even after the period of almost 3000 years, it's utility is accepted more than the past years. Many scientists are working on its fundamentals and getting the results as mentioned. So it is the favorite book of the Vaidyas. All this credit goes to Agnivesha, Charaka and Dridhabala but especially to Charaka as he elaborated and renewed the text and gave the shape of Samhita which is more palatable. No doubt he is the great legendary and visionary in the field of Ayurveda.

4.2.4. Patanjali

Several important Sanskrit works are ascribed to one or more authors of this name. Amongst the more important authors called Patanjali are the author of the Mahabhasya, an advanced treatise on Sanskrit grammar and linguistics framed as a commentary on Katyayana's varttikas (short comments) on Paṇini's Aṣṭadhyayi. The compiler of the Yoga Sutras, an important collection of aphorisms on Yoga practice, who according to some historians was a notable person of Samkhya, contemporaneous with Ishvarakrishna's Samkhya-karika around 400 CE and also the author of an unspecified work of medicine (Ayurveda).

4.2.4.1. Name

The compound name Patanjali has been explained by Sanskrit commentators in two ways. The first explanation of the word is anjalau patan iti patanjali (Patanjali is one falling into folded hands), which is a mayuravyamsakadi compound with sakandhvadi Sandhi. The name comes from a legend about his birth which says that Seṣa, the divine serpent-king, incarnated as a snakelet and fell into the folded hands (Anjali Mudra) of a Brahmin. The second explanation parses the word as a Bahuvrihi compound patanto namaskaryatvena jananamanjalayo yasmin viṣaye sa (He for whom the folded hands of people are falling is Patanjali). The compound name Patan jali: "Patan" is 'bank' and "Jal" is 'water', in the Sindhi language of the Indus Valley Civilization.

4.2.4.2. His parents and his birth

The dates proposed for Patanjali's birth and life vary by a millennium. Some authorities suggest that he lived and flourished in the 4th century BCE, while others insist that he must have lived in the 6th century CE. A part of the reason for this wide divergence in possible dates is the tradition, common at the time (it existed also in contemporary Greek society and still causes endless problems for historians), to ascribe anything worth saying to someone already acknowledged as a great exponent. In order to make their contributions more acceptable, and to give them some cachet and an air of authority, later thinkers were frequently content to concede authorship of their contributions to one or another of their more illustrious predecessors. Those predecessors thus acquired an exaggerated longevity. In the face of the conflicting evidence the best that can now be done is to come up with a consensus for the most likely dates for Patanjali's birth and death. Given that the knowledge in Patanjali's most widely recognized work, the Yoga Sutras, is presented through a series of terse aphorisms, a date for him of somewhere between the fourth and second centuries BCE becomes highly likely. It was over that period that the aphorism style not only gained extensive acceptance, but reached probably its greatest stylistic peak. Patanjali's work is widely regarded as the finest example extant of the sutra method of presentation. Give or take a century, therefore, somewhere around 250 BCE seems the best bet.

Trying to determine Patanjali's parentage poses further problems. According to one legend he was the son of Angiras, one of the ten sons of Brahma, the Creator; and of Sati, the consort of Siva. If so, this would make him not only the grandson of the Creator of the universe, but also the brother of Brhaspati, god of wisdom and eloquence and chief offerer of sacrifices.

According to another legend, shortly before Patanjali was born the Lord Vishnu was seated on his serpent, Adisesa. (Adisesa is in fact one of the many incarnations of Vishnu). While seated on his serpent carriage Vishnu was enraptured by the dancing of Lord Siva. Vishnu was so affected that his body began to vibrate causing him to pound down heavily on Adisesa-who consequently suffered great discomfort. When the dance ended the weight was instantaneously lifted. Adisesa asked Vishnu what had happened. On hearing about the dance Adisesa wanted to learn it so he could personally dance it for the pleasure of Vishnu, his lord. Vishnu was impressed and predicted to Adisesa that one day Lord Siva would bless him for his understanding and devotion and that he would be incarnated so that he could both shower humanity with blessings and fulfill his own desire to master dance. Adisesa immediately began to ponder on the question of who his mother would be. At the same time a virtuous woman named Gonika, who was totally devoted to yoga, was praying and seeking for someone to be a worthy son to her. She wanted to pass on the knowledge and understanding she had gained through yoga. Concerned that, with her days on earth now severely numbered, she had not yet found a candidate, she prostrated herself before the Sun, the earthly manifestation of the light and presence of God. She scooped up the only gift she could find-a handful of water-and beseeched him to bestow her with a son. She then meditated upon the Sun and prepared herself to present her simple but sincere offering. On seeing all this Adisesa-the bearer of Vishnu-knew that he had found the mother he was looking for. Just as Gonika was about to offer her handful of water to the Sun, she glanced down at her hands and was astonished to see a tiny serpent moving in her hands. She was even more astonished when, within a few moments, that serpent had assumed a human form. Adisesa, who it was, in his turn prostrated before Gonika and pleaded with her to accept him as her son.

4.2.4.3. His place of birth

As for where Patanjali was born-this, also, is far from clear. Nor is it clear exactly where he lived. Tradition holds that Sage Patanjali was not born in Bharatavarsha-i.e. in any ordinary place. He was rather born in Ilavritavarsha. Some insist that Ilavrita is not one of the divisions of Jambudvipa at all but an exalted place beyond. It is inhabited only by gods and those few spiritual beings who embody supreme spirituality and transcendence. Ilavrita, therefore, is not strictly a part of India, or any other earthly country, but an ethereal and celestial abode.

In order to appease those who always want to be literal, and who will settle for nothing less than verifiable facts, it is probably wisest to concede that all these tales of Patanjali's birth and his likely domicile are most probably allegories. So it could be that what is being implied is that, in common with all those other great rishis and seers who have benefitted humanity, Patanjali came to these earthly times and places from some completely other sphere. He came to elucidate knowledge for the benefit of those dwellers in Bharata who-afflicted as they are by time, existence and the workings out of causes and effects-are still nevertheless eager to receive and imbibe it.

4.2.4.4. His life

However and wherever he was born, Patanjali eventually appeared on earth to fulfill his self-appointed destiny. Unsurprisingly, given his lineage, he had no ordinary childhood. He could apparently communicate fully from the moment he was born. Not only that, but both the topics of his conversations and the intellect and vigour with which he discussed them were of the kind more usually associated with sages, rishis and seers. Patanjali not only acutely and accurately analysed and discussed things of the present, but revealed matters of both the ancient past and the immediate and distant futures with accuracy and incisive penetration. The cut and thrust of his eye, mind and mouth were of such intensity that on one occasion, when the inhabitants of Bhotabhandra chose to disturb him in the middle of his religious austerities and ridiculed him, he reduced them to ashes with nothing more than the fire of his mouth and speech. His marriage is also the stuff of legend. One day he seems to have discovered an exquisitely and enchantingly beautiful maiden, Lolupa, in the hollow of a tree on the north slope of Mount Sumeru-the top of the celestial mountain of enlightenment. He promptly married her, thus indissolubly joining himself to the fruits of his spiritual quest, and lived to a ripe and happy old age.

4.2.4.5. His portrayal and iconography

As portrayed in the photograph above, Lord Patanjali is reckoned to be an incarnation of the serpent Ananta, whose name means 'the endless one'-and who is another form of Adisesa. He is therefore, on some accounts, Lord Vishnu's seat, for Vishnu sits upon Adisesa before the beginning of creation.

Above Patanjali is the cobra's hood, the sign of ultimate protection from all possible evils and difficulties in the world. There are seven serpent hoods forming a divine umbrella protecting both Patanjali and all aspirants who turn to him for guidance. Those seven hoods symblize his mastery and conquest of the five elements of earth, water, fire, air and ether, along with the attainment of moksha and samadhi, liberation and enlightenment.

Patanjali himself is generally depicted as half human and half serpent. His human torso emerges from the coils of the all-powerful serpent, who is awakening in the moment of creation. The serpent embodies that creative energy. It is coiled three and a half times. There is one coil each for the earth, the atmosphere and the heavens. Or, again, one coild each to represent his omnipresent, omnipotent and omniscient natures. And then a further half-coil to show that he sets aside the material nature, rises above them all, and is absorbed only in the world seen in meditation, being free from everything else.

Patanjali's hands are in the traditional Indian greeting of 'namaste'-sometimes called an 'añjali' or offering. Since 'pata' means fallen, 'Patanjali' can be roughly translated as 'the grace (or "the grace-full one") that falls from heaven'.

The lord is generally depicted in a meditative trance. His folded hands are both blessing and greeting those who have approached him seeking yoga and its truths. His salutation eases their labours with its grace. It also assures them that those labours will eventually bear fruit. Patanjali in fact has not two, but four hands. The two immediately in front of him create the blessings of the añjali while the other two are raised. One of the uplifted hands holds sankha, the conch that embodies the energy of sound. It both calls students to practice and announces the imminent ending of the world as they have so far known it. His other uplifted hand holds the cakra or discus that embodies both the turning wheel of time and its associated law of cause and effect.

4.2.4.6. His achievements

When it comes to determining what Patanjali did, the uncertainties continue. A first achievement, which is not surprising given the tales of his parentage, is his recognition as a truly great dancer. To this day dancers in India working in the classical traditions invoke him and pay him their respects. Patanjali, therefore, is effectively the patron saint of dance.

Some say that Patanjali also wrote a treatise on ayurvedic medicine. Certainly, the texts in question focus on what could well have been Patanjali's main interests: the diagnosis of disease; the structure and function of the human body; the problem of keeping the body fit, pleasing-feeling and good looking; and the curative values and properties of drugs and the techniques required to administer them. All these are mentioned in the Yoga Sutras. But although a strong tradition does insist that the Patanjali who wrote the ayurvedic text is the self-same Patanjali who wrote the Yoga Sutras, scholars do not accept this as an established fact. But an argument that can be made against these scholarly types is that they are rather missing the point. Svayambhus-divine beings who bring about their own causeless existences, who are without karma, and who manifest themselves as evolved and highly spiritual beings for the betterment of humanity-are in no way obliged to respect historical facts.

The waters are further muddied when it comes to another great treatise attributed to Patanjali. It is beyond dispute that a famous man named Patanjali was born in Gonarda and that he lived, for at least a little while, in Kashmir. This particular Patanjali lived and wrote in about 140 BCE. He was a great grammarian and his Mahabhashya or Great Commentary on Panini's grammar (the first great grammar written for any language) was magisterial. It is still read and acknowledged today. But the Mahabhashya was a lot more than just a commentary. The Patanjali who wrote it took Panini's work a great deal further. He redefined the rules of Sanskrit grammar. He greatly enlarged its vocabulary. He gave Sanskrit a muscular power that made it a more precise, subtle, effective and artistic instrument capable of expressing any aspect whatever of human thought or existence. Furthermore, this Patanjali did not just provide a body of theory. He demonstrated the possibilities of Sanskrit through his skills and artistry in its use.

Clearly, the question of the moment is whether the Patanjali who wrote the Mahabhashya was (a) the same as the Patanjali who wrote on ayurveda; and/or (b) the same as the Patanjali who wrote on yoga (never mind (c) the same as the one who was a founding father of dance).

Focusing on grammar and yoga, there is the inevitable initial problem of validating the necessary contemporaneous dates and locations. Although it is not conclusive, the best evidence is in the negative. The Patanjali of the Yoga Sutras surely lived several centuries before the Patanjali of the Mahabhashya. There is not (as) much leeway in the dates for the latter. Added to this is some internal evidence. Philosophical contradictions between the two texts would seem to indicate that they simply cannot have had the same author. This, however, is a far from convincing argument. It is easy enough, after all, to find writers who express contradictory ideas on the same page never mind in such different books, on such vastly different subjects, and written at different points in their lives. Furthermore, a work of grammar is a very different animal from a book on yoga. It is surely not to be wondered at, then, if ideas that show themselves to best advantage in the one field are not in any way efficacious—and, indeed, cause great difficulties—when carried over to another. The point is surely that both are excellent self-contained works with impeccable arguments and logical structures in their respective fields. This is surely exactly what they should be. It is true that it would be neat if it were otherwise but, at the end of the day, there is no reason why the one work is obliged to make reference to, or be 100% compatible with, the other.

All told, the tradition that conflates these three Patanjalis (four if dance is added to grammar, medicine and yoga) into one has been around some two millennia ... and it is not about to die out any time soon.

4.2.4.7. His contribution

Unfortunately, the confusion about Patanjali's life permeates the very thing for which he is the most famous: the Yoga Sutras. There is uncertainty about (at least) three important things. Did Patanjali actually write the Yoga Sutras? If he did, did he make an original contribution or was he 'merely' a collator and systematizer? And assuming that the answer to the first question is affirmative, is the text we have today what Patanjali actually wrote?

Probably the greatest controversy concerns the fourth pada or chapter of the Yoga Sutras. Some commentators argue that its style and content are very different from the first three. For one thing, it is exceptionally short. This brevity would not amount to much if it were not for the structure of its argument. The first three chapters seem to develop their themes in a leisurely and non-dogmatic manner. The fourth, by contrast, seems much more rushed. It has the air of striving earnestly to make a point. Sutra 16 is probably the most controversial of all in that it seems to have been lifted from Vyasa's seventh commentary. At one point Vyasa seems to be expounding on Patanjali and countering arguments raised by Buddhism. At another moment he seems to be saying that a particular sentence he is elucidating is in any case something Patanjali said. But-it is unclear if Patanjali actually said it, or if Vyasa merely says he did.

Another bone of contention is that, unlike the first two chapters, the third ends with 'iti'. 'Iti' has the rough meaning of 'thus as it was intended' (somewhat like the QED or quod erat demonstrandum of mediaeval and Renaissance geometric texts). It is the traditional way of ending a Sanskrit text-meaning that there seem to be two 'The End's in one book. The critics declare that it is most curious that one book should contain two 'iti's or 'The End's.

Those who prefer to affirm the unity of the Yoga Sutras are unconvinced by the above arguments. They point out that the fourth chapter is physically and metaphysically coherent with the previous three and that the four, taken together, achieve a remarkable degree of homogeneity and thematic consistency. All the fourth chapter does is describe the same topic-but from the standpoint of one who has succeeded rather than one who is still seeking. The sceptics promptly counter by saying that anyone wanting to pass off an obviously later interpolation as a part of the original would have gone to exactly this kind of trouble. Clearly, it is important to settle whether the first three chapters, which both sides use as their measuring stick, are indisputable as Patanjali originals. Settling even this becomes difficult because the status of some sutras (with sutra 22 in Chapter III being probably the most famous example) has also been questioned. It, also, say the critics, seems to be a later interpolation in that it disturbs an otherwise smooth flow. The obvious response is then made. This authenticity debate is not one that can really be resolved.

As for what precise contribution Patanjali made, this is also hard to settle. Yoga, or some yoga-like subject, definitely existed before him. The oldest of the Upanishads make unequivocal references to, for example, pranayama, the science of the breath. The later Katha Upanishad, amongst half a dozen others of the same vintage, indicates that that era already enjoyed several different systems of yoga. This differentiation bespeaks a long ancestry. The more specifically yogic Upanishads, such as the Hamsa, the Yogatattva, the Yogakundali and some half a dozen others, are later still and give instructions-admittedly obscure-for asanas and other yogic disciplines. Although yoga is ultimately about practice, it is also a philosophy and a metaphysic. Of the Upanishads, probably only the Maitrayana has a distinct leaning towards the Sankhya philosophy-something that is essential for the full emergence of yoga as a system of thought. Yoga is complementary to Sankhya. It has the goal of realizing the Spirit from within the world of nature as discussed in Sankhya. By the time of the Mahabharata—the great epic that is effectively the early history of India-both Sankhya and Yoga are being taken for granted as pre-existing and already ancient systems of thought. It is therefore appropriate that they have founders. Kapila has become the fountainhead for Sankhya while Hiranyagarbha fulfills a similar role for yoga. According to the Ahirbudhnya, Hiranyagarbha revealed the whole of yoga in the Nirodha Samhita and Karma Samhita. And ... it is surely beyond coincidence that the second sutra of the Yoga Sutras defines yoga in terms of nirodha. Not only that, but the Nirodha Samhita is often called the Yoganushasanam ... the very words with which Patanjali begins the Yoga Sutras. If Patanjali did make original contributions then he borrowed heavily from pre-existing trends in Sankhya and Yoga.

As to the question of originality, although Patanjali is clearly of the lineage of Hiranyagarbha and Kapila, he does differ from them in important respects. This could have been because he had genuinely had ideas of his own. But yoga was strongly associated with the shramana tradition, these being wandering forest mendicants and seekers. It therefore encouraged independence of thought. So Patanjali could just as well have been trying to bring order to a system with widely divergent methods. Some insist that 'all' he did was bring together and summarize a varied body of texts most of which have now been lost. Whatever was his inspiration, Patanjali does seem to have propounded many ideas that were not of the mainstream in either Sankhya or Yoga. He recognizes ego, for example, but does not accept it is a separate principle. He recognizes the subtle body but does not regard it as permanent. He also denies that it can operate directly on external things. These ideas differ from the mainstream, at that time, in both Sankhya and Yoga. Like all others concerning Patanjali the question of what is original with him is well nigh impossible to settle. The Yoga Sutras could easily have been his original thoughts on both Sankhya and Yoga. On the other hand, he could have been reinterpreting and clarifying what others had said, freeing them at the same time from contradictions. The very least that can be said is that he brought many threads, some dating back to the Vedas and Upanishads, together; and that he did so with what modern psychology would call genius. What had previously been long-winded and obscure he encapsulated in the nuggets of his sutras; and what had previously been abstract he made practical and easy to validate through the lives and experiences of a long line of teachers and practitioners. While the Yoga Sutras initially appears to be a dry and theoretical text, it explains human nature and psychology while also being an intensely practical manual for spiritual advancement.

Ultimately, the historical uncertainties concerning Patanjali are of little concern to those who wish to achieve some measure of success in the things of which he wrote: gaining inner tranquillity and attaining spiritual realization. Its authorship and genesis may be contested but the Yoga Sutras is a coherent and self-sustaining whole that supports the seeking aspirant on theoretical and practical levels.

4.2.5. Conclusion

Medical Science in the form of Ayurveda is the indigenous system of medicine that was developed in Ancient India. Susruta’s greatest contribution was in the fields of Rhinoplasty (plastic surgery) and Ophthalmic surgery (removal of cataracts). Charak Samhita, written by Charak is a remarkable book on medicine. This ancient Indian system of medicine not only helps in treatment of diseases but also in finding the causes and symptoms of diseases. It is a guide for the healthy as well as the sick. The main aim of ayurveda has been health and longevity. It is the oldest medical system of our planet. The science of Yoga was developed in ancient India as an allied science of Ayurveda for healing without medicine at the physical and mental level. Yoga, sets in to motion the force that purifies and uplifts the consciousness to divine realization. Yoga is physical as well as mental. The credit of systematically presenting this great science goes to Patanjali. Patanjali wrote Yogasutra and grammar book known as Mahabhasaya.

4.2.6. Summary

- *Medical Science in the form of Ayurveda is the indigenous system of medicine that was developed in Ancient India.*
- *The word Ayurveda literally means the science of good health and longevity of life. Charak is called the father of ayurvedic medicine and Susruta the father of surgery in ancient India.*
- *Susruta's greatest contribution was in the fields of Rhinoplasty (plastic surgery) and Ophthalmic surgery (removal of cataracts). Charak Samhita, written by Charak is a remarkable book on medicine.*
- *This ancient Indian system of medicine not only helps in treatment of diseases but also in finding the causes and symptoms of diseases. It is a guide for the healthy as well as the sick.*
- *Ayurveda defines health as an equilibrium in three doshas, and diseases as disturbance in these three doshas. While treating a disease with the help of herbal medicines, it aims at removing the cause of disease by striking at the roots.*
- *The main aim of ayurveda has been health and longevity. It is the oldest medical system of our planet.*
- *The science of Yoga was developed in ancient India as an allied science of Ayurveda for healing without medicine at the physical and mental level.*
- *The term Yoga has been derived from the Sanskrit work Yoktra. Its literal meaning is "yoking the mind to the inner self after detaching it from the outer subjects of senses". Like all other sciences, it has its roots in the Vedas. It defines chitta i.e. dissolving thoughts, emotions and desires of a person's consciousness and achieving a state of equilibrium.*
- *It sets in to motion the force that purifies and uplifts the consciousness to divine realization. Yoga is physical as well as mental. Physical yoga is called Hathyoga. Generally, it aims at removing a disease and restoring healthy condition to the body. Rajayoga is mental yoga. Its goal is self realization and liberation from bondage by achieving physical mental, emotional and spritiual balance. Yoga was passed on by word of mouth from one sage to another.*
- *The credit of systematically presenting this great science goes to Patanjali. In the Yoga Sutras of Patanjali, Aum is spoken of as the symbol of God. He refers to Aum as a cosmic sound, continuously flowing through the ether, fully known only to the illuminated. Besides Yoga Sutras, Patanjali also wrote a work on medicine and worked on Panini's grammar known as Mahabhasaya.*

4.2.7. Exercise

- Write an essay on the biography and contribution of Susruta to Ayurveda.
- Discuss the life and works of Charak for the growth of Ayurveda in ancient India.
- Define Auyrveda. Discuss the process of surgery as illustrated by Susruta in his work.
- Discuss the idea of pharmacology in Ayurveda as narrated by Charak in his Samhita.
- Give and account on the life and contribution of Patanjali to Indian culture.

4.2.8. Further Reading

- Dasgupta, Surendranath., A History of Indian Philosophy, Motilal Banarsidass Publications , 1992, Volume 1.

- Radhakrishnan, S., and C.A. Moore., A Source Book in Indian Philosophy. Princeton, New Jersey: Princeton University, ch. XIII, Yoga, ,1957.
- Raghavan, V., (et al) New Catalogus Catalogorum. Madras: University of Madras. pp. vol. 11, pp. 89–90. lists ten separate authors by the name of "Patanjali." 1968.
- Renou, Louis., "On the Identity of the Two Patanjalis", In Narendra Nath Law, Louis de La Vallée Poussin Memorial Volume. Calcutta, 1940.
- Sharma, P.V. Article on Charaka. In, P.V.Sharma's History of medicine in India (from antiquity to 1000 A.D.), Indian National Science Academy, New Delhi, India, First print: 1992.
- Thapar, Romila., Interpreting Early India. Oxford University Press, 1992.
- Woods, James Haughton., (ed), The Yoga Sutras of Patanjali, Published for Harvard University by Ginn & Co., 1914.

*****

Unit-4
Chapter-III
SCIENTISTS OF MODERN INDIA:
Jagdish Chandra Bose, Srinivas Ramanujan, C.V. Raman, Homi Jehangir Bhabha and Dr. Vikram Sarabhai.

Structure

4.3.0. Objective

In this chapter we intended providing you an insight into the career and achievements of some of the distinguished torch bearer of Indian sciences in the modern times. By the end of this chapter the learners would be able to:

- *understand the career and achievements of Jagadish Chandra Bose;*
- *trace the early life and contribution of Srinibas Ramanujan in the sphere of Mathematics ;*
- *survey the circumstances led to the award of Nobel prize to C.V.Raman;*
- *describe the growth of Nuclear energy in India under Homi Jahangir Bhabha;*
- *discuss the career and contribution of Vikram Sarabhai in the space science in India.*

4.3.1. Introduction

The last decades of the nineteenth and early decades of the twentieth century witnessed a national awakening in all spheres of creativity. The 'Indian renaissance' also produced outstanding scientists. Fired by nationalism, disregarding comforts, and undeterred by severe handicaps, these men did world-class science by indomitable will. We stand on their shoulders today. They are instrumental in building up the vast and rich scientific culture of modern India. All those chosen here have contributed immensely to science. Almost all have been great institution builders. This chapter will throw brief sketches of life and works of the torch bearers and try to present their travails and triumphs.

4.3.2. Jagdish Chandra Bose(1858-1937)

On November 30, 1858, at Mymensingh (now in Bangladesh), a son was born to Bhagawan Chandra Bose and Bama Sundari Devi. The child was named Jagadis or Lord of the World. True to his name J. C. Bose grew up to be known as a scientist of world repute. Young Jagadis spent the early years of his life in Faridpur where his father was posted as the Deputy Magistrate. It was the time spent in Faridpur that Bose would value greatly in his later years. He was brought up in a house steeped in Indian tradition and culture and was sent to the village *pathshala* to study with the common folk. As he spent time with sons of farmers and fisher folk, he learnt the lesson of what constitutes true manhood. From them he also drew his love for nature.

4.3.2.1. Early Childhood and Education

Young Jagadis was a curious lad, always asking questions. The fast-moving river with fallen leaves floating by, the sprouting of seeds and growth of plants, the attraction of the moth towards light, the shooting stars, all were curiosities he was impatient to understand. He would not rest till he found a satisfactory answer. His father was always there to respond to his childhoods curiosity and encouraged him, saying as you grow bigger and bigger, my boy, try to find out the truth yourself. However, it was not all work and no play for Jagadis, who loved sports too. Cricket was his favourite game. At the age of nine Jagadis was sent to Calcutta. There he enrolled first at Hare School and later, in St. Xaviers where his lack of proficiency in English made him the butt of jokes. His European classmates refused to accept this rustic boy as one of them. One day unable to tolerate the bullying from a champion boxer, he took up the challenge. In the fight that followed Jagadis won and gained the respect of his classmates. Thereafter, no one dared to tease him.

At St. Xaviers, Jagadis studied physics under Father Lafont who was then a name to conjure with for his brilliant and unique methods of teaching physics with actual experiments. From him too, he picked up the flair for lecture demonstrations. However, botany continued to enthrall him. He would pull out germinating plants to check their roots and grew flowering plants and closely observed their growth. Jagadis passed the School Final examination with a First Class. After graduating at the age of 19, Jagadis had a strong desire to go to England and sit for the Indian Civil Service Examination, but his father would not allow him to do so. He told his son in no uncertain terms that he was to rule nobody but himself, was to become a scholar, not an administrator. Hence, in 1880, Jagadis did go to England but to study medicine at the University of London. There, he suffered repeated attacks of malaria, which he had contracted prior to his departure for London and had to move to Cambridge on a scholarship to study Natural Science at Christs College. At Cambridge, he came under the influence of such illustrious teachers as Lord Rayleigh, Sir James Dewar, Sir Michael Foster and Francis Darwin.

4.3.2.2. Early Career

Jagadis passed the Tripos examination with distinction. In 1884, he was awarded a B.A. degree from Cambridge and next year a B.Sc. degree from London University. Once he got his degrees, he did not linger abroad but returned to serve his motherland. In 1885, he was offered the post of officiating Professor of Physics at Presidency College, Calcutta. He was paid a salary half of what the British teachers were paid, so Bose refused to draw his salary at all as a protest. He worked in an honorary capacity for three years, not missing his classes even on a single day .

In England, Bose had appreciated the 'hands on' approach to science. Back in India, he carried on in the same spirit. Instead of boring verbal lectures, he enlivened his classes by holding extensive demonstrations. This was quite an innovation in those days and Bose became extraordinarily popular with his students. He encouraged them to observe, to question, to experiment and to innovate, without depending solely on books or teachers. After three years, the college Principal Twany and Director Croft, impressed by his brilliance, jointly recommended full salary for him from the date of his joining the college. Bose realized that the best way to face the English was to face them with courage and will power. This he did all his life.

In 1887, Bose married Abala Das, daughter of a leading advocate of the Calcutta High Court and a political leader. Bose's wife was his constant companion and helpmate, accompanying him on his trips to religious and historical places in India and on many excursions to the Himalayan peaks and glaciers. Later in life, she joined her husband on all his lecture tours abroad. Bose dedicated his book *Plant Autographs and their Revelation* (1927) to Abala Devi with the note, To my wife, who has stood by me in all my struggles.

4.3.2.3. Scientific Experiment

When Bose first joined the Presidency College, there was no laboratory worth the name. However, Bose went ahead with his research, in a small enclosure adjoining a bathroom that he converted into a laboratory where he carried out experiments on refraction, diffraction, and polarization. Bose would stay on in the laboratory after the classes were over and carry on experiments. He met the expenses for the experiments himself. He even fabricated the equipment he needed by sheer ingenuity. The experiments performed in the makeshift laboratory finally resulted in the invention of a device for producing electromagnetic waves.

In November 1894, Bose gave the first public demonstration of wireless transmission using electromagnetic waves to ring a bell and to explode a small charge of gunpowder from a distance. He used microwaves with wavelengths in the millimeter range, not radio waves. Considering the very primitive workshop facilities available in Calcutta at this time, the compact nature of his apparatus excited many and drew a great deal of appreciation in England. It was described in many textbooks of this period by J. J. Thomson and Poincare. The Daily Chronicle (England) reported, the inventor has transmitted signals to a distance of nearly a mile and herein lies the first and obvious and exceedingly valuable application of this new theoretical marvel. It was more than a year after the successful demonstration of his experiment that Guglielmo Marconi patented this invention. It is believed that it was Bose's failure to seek a patent that denied him his due. However, by all accounts, Bose was never interested in money. The British navy was interested in his coherer (device that detects radio waves) to establish radio links between ships and torpedo boats.

Later, Bose developed the use of Galena crystals for making receivers, both for short wavelength radio waves and for white and ultraviolet light. His pioneering work in the field was recognized by his peers. Sir Neville Mott, who won the Nobel Prize in 1977 for his contributions to solid state electronics, went on record stating that, J.C. Bose was at least sixty years ahead of his time.... In fact, he had anticipated the existence of P-type and N-type semi-conductors. Bose's first paper published in the Proceedings of the Asiatic Society of Bengal in May 1895, deals with the polarization of electric waves by double refraction. In

October 1895, his first communication to the Royal Society of London was published in its Proceedings. The next year, he was conferred D. Sc. by London University for his thesis on Measurements of Electric Rays, Bose went to England in 1897, where he not only repeated his demonstrations successfully but also speculated on the existence of electromagnetic radiation from the sun. Two years later, Bose unveiled his invention of the mercury coherer with the telephone detector. The same year he unfortunately lost his diary containing the account of his invention and a prototype of the detector.

Bose devoted a great deal of attention to the peculiar behaviour of his coherer, which consisted of a number of contacts between metal filings whose resistance altered under the impact of electric radiation. Detailed investigation led him to the view that this coherer effect was characteristic of a large class of compounds, like selenium, iron oxides, etc. In fact, Bose can be considered a pioneer in the field of investigation of the properties of photoconductivity and contact rectification shown by this class of semi-conductors. His subsequent study of the fatigue phenomena exhibited by these substances led Bose to postulate his theory of the similarity of response in the living and the non-living. He found that the sensitivity of the coherer decreased when it was used for a long period -it became tired. When he gave the device some rest, it regained its sensitivity which, in his view, indicated that metals had feelings and memory.

During 1897-1900, Bose turned his interest to comparative physiology, plant physiology in particular. The main focus of his investigations was to establish that all the characteristics of response exhibited by animal tissues are equally exhibited by plant tissues. In 1901, Bose submitted to the Royal Society a preliminary note on the Electric Response of Inorganic Substances, in which he showed how he had obtained strong electric response from plants to mechanical stimuli. However, the paper was not published due to the opposition of Sir John Burdon Sanderson, the leading electro-physiologist of the time. In 1904, Bose submitted a series of papers, once again to the Royal Society, showing the similarities of both the electric and mechanical responses of plants and animals. But these papers too met the same fate.

His interest in physiology gave an impetus to his inventive genius. For obtaining the records of mechanical response of plant tissues, he first introduced the optical lever in plant physiology to magnify and photographically record the minute movements of plants. He perfected the resonant recorder that enabled him to determine with remarkable accuracy, within a thousandth part of a second, the latent period of response of the touch-me-not plant, Mimosa pudica. He also devised the oscillating recorder for making minute lateral leaflets of the telegraphic plant automatically record their pulsating movements. He even took up the problem of recording micrographic growth movements of plants by devising the crescograph. With this instrument, he obtained a magnification of 10,000 times, and was able to record automatically the elongation growth of plant tissues and their modifications through various external stimuli. Later, he perfected his magnetic crescograph obtaining a magnification from one to ten million times. A demonstration of the crescograph at the University College of London on April 23, 1920 led several leading scientists to state in The Times: We are satisfied that the growth of plant tissues is correctly recorded by this instrument, and at a magnification from one million to ten million times.

4.3.2.4. Recognition and last days

The 1900s marked a spell of renewed activity. He attended international conferences and wrote books and research papers. In 1903, he was conferred Companionship of the British Empire (C.B.E.) by the British government. In 1912, he received the Companionship of the Star of India (C.S.I.). The University of Calcutta conferred on him an honorary D.Sc. The Royal Society which had been publishing his papers on physical research since 1894, but had raised serious objections to his physiological research, honoured him in 1920 by electing him a Fellow. In 1933 and 1935, Banaras Hindu University and Dhaka University, respectively, awarded him honorary D.Sc. He formally retired from Presidency College in 1915, but was appointed Professor Emeritus for the next five years. Bose was not interested in making money. He could have made millions by simply patenting his inventions but more important for him was to spread knowledge. Towards this end, he had nurtured a lifelong dream of establishing an institute of excellence.

Conceived at least twenty years earlier, the Bose Institute was inaugurated in Calcutta on November 30, 1917. This is not a laboratory, he had said, about his Institute, but a temple. Bose died on November 23, 1937, just a week short of his eightieth birthday.

4.3.3. Srinivasa Ramanujan(1887-1920)

4.3.3.1. Early Childhood and Education

Srinivasa Aiyangar Ramanujan was born in Erode, in Tamil Nadu, on December 22, 1887. His father worked as a petty clerk in a cloth factory. After attending primary school in Kumbhakonam, he entered the Town High School in 1898. From early childhood it was evident that he was a prodigy and at the age of 13, he had already plunged into serious arithmetic and geometry. The turning point in his life came when he chanced upon the book Synopsis of Elementary Results in Pure and Applied Mathematics, by George Shoobridge Carr. The book contained theorems, formulae and short mathematical proofs. It also contained an index to papers on pure mathematics published in the European journals of learned societies during the first half of the nineteenth century. It was this book that triggered the mathematical genius in him. He discovered the relationship between circular and exponential functions. From that moment onwards, Ramanujan's mind was flooded with mathematical ideas and so many of them that he would solve the problems on loose sheets of paper and jot down the results in his notebooks. The notebooks would later become famous as Ramanujan's frayed notebooks. Even today mathematicians are studying them to prove or disprove those results.

4.3.3.2. Admiration for Mathematics

After a first class in mathematics in the matriculation examination Ramanujan entered the Government College in Kumbhakonam in 1904. He was also awarded the Subramanyam scholarship. During that time Ramanujan was particularly interested in relations between integrals and series. In 1906, Ramanujan went to Madras where he enrolled at Pachaiappa's College. He failed twice in the first year arts examination, because he neglected other subjects such as history, English and physiology. Soon he fell ill and had to leave the college. Later, he sat for the examination and again passed only in mathematics. In 1908, he fell seriously ill and in April 1909 had to undergo an operation. But even during his illness Ramanujan was driven by his passion for mathematics, always scribbling numbers. Fearing for his sanity, his parents married him off to S. Janaki Ammal, then only eight or nine years old, hoping that marriage would bring him around to the real world. But this only thrust upon him a responsibility he was not ready for. He began to look for a job but his unkempt and unimpressive visage did not get him very far. Wherever he went he showed his frayed notebooks and told people that he knew mathematics and could do clerical jobs. No one could understand what was written in the notebooks and his applications were turned down.

In 1911, he approached Ramachandra Rao, Collector at Nellore and the founder-member of the Indian Mathematical Society. This is what Rao wrote about their first encounter, A short uncouth figure, stout, unshaven, not over-clean, with one conspicuous feature--shining eyes, walked in with a frayed notebook under one arm. He was miserably poor. He ...began to explain.....but my knowledge did not permit me to judge whether he talked sense or nonsense...I asked him what he wanted. He said he wanted a pittance to live on so that he might pursue his research. Rao tried unsuccessfully to arrange for a scholarship for Ramanujan. Ultimately, Ramanujan did find what he was looking for, a clerical job. Francis Spring, the Director of the Madras Port Trust, gave Ramanujan a clerical job on a monthly salary of Rs. 25. Later, some teachers and educationists interested in mathematics who had seen Ramanujan's work, initiated a move to provide him with a research fellowship.

4.3.3.3. Ramanujan in England

In 1913, Ramanujan sent a letter to G. H. Hardy, the renowned mathematician of Trinity College. He set out 120 theorems and formulae. He also gave a key formula in hyper geometric series, which came to be known after him. Hardy would have ignored the letter from an obscure Indian but as fate would have it, he glanced at the theorems included and was instantly hooked. As Hardy later said, No one would have had the imagination to cook them up. It did not take long for Hardy to realize that they had discovered a mathematical genius. Only a mathematician of the highest class could have written those theorems.

Subsequent correspondence with Ramanujan was enough to convince Hardy that here indeed was a genius. He asked Ramanujan to come over to England and even made arrangements for Ramanujan's passage and stay at Cambridge University. All through this eventful decade of Ramanujan's short life, the Madras University came to his help thrice. It offered him the first research scholarship of the University in May 1913; then it offered him a scholarship of 250 pounds a year for five years with 100 pounds for passage by ship and for initial outfit to go to England in 1914; and finally, it granted Ramanujan 250 pounds a year as an allowance for five years commencing from April 1919, soon after his triumphant return from Cambridge with a scientific standing and reputation such as no Indian has enjoyed before. On March 17, 1914, Ramanujan sailed for Britain. But his decision to travel abroad was not without its usual share of drama, for it raised quite a few eyebrows in his family, as foreign travel by devout Hindus was frowned upon in those days. The story goes that the family deity, Goddess Namagiri, appeared in a dream and parental permission was subsequently granted for the voyage.

Ramanujan arrived in Cambridge on April 14, 1914 and found himself a total stranger there. Coming from the sunny climate of India, the English cold was hard to bear. Also, being a Brahmin and a vegetarian, he had to cook his own food. However, all through this hardship one factor remained constant that is his interest in mathematics. And the company of Hardy and Littlewood made him forget much of his hardship. During his five years stay in Cambridge, he published 21 papers, five of which were in collaboration with G.H. Hardy. His achievements at Cambridge included the Hardy-Ramanujan circle method in number theory and Roger-Ramanujan identities in partition of integers. He worked on composite numbers, algebra of inequalities, probability theory, continued fractions, and so on. Hardy always regretted that he had not chanced upon Ramanujan during the most fertile years of the latter's life which were spent battling poverty and neglect. Hardy also found Ramanujan an unsystematic mathematician.

In 1916 Ramanujan was awarded the B.A. degree by research of the Cambridge University. He was elected a Fellow of the Royal Society of London in February 1918. In October the same year he was elected to a Trinity College Fellowship-the first Indian to be elected Fellow of Trinity College. He received a prize fellowship worth 250 pounds a year for six years with no duties or conditions attached. But Ramanujan was not destined to live long enough to enjoy either fame or prosperity. His health began to fail. Tuberculosis had begun devouring him. He spent a long time in hospitals. His mind, however remained razor sharp. Once, Hardy visiting him in the hospital mentioned that the number of the taxi he had come in was 1729, and that he thought it was rather a dull number. From his sick bed, Ramanujan protested, No, Hardy, it is a very interesting number. It is the smallest number that can be expressed in two different ways as the sum of two cubes. As usual he was right because 1729 can be written as 103+93 and also as 123+13. Failing health forced Ramanujan to return to India. Hardy, his mentor wrote, He will return to India with a scientific standing and reputation such as no Indian has enjoyed before, and I am confident that India will regard him as the treasure he is. His natural simplicity and modesty has never been affected in the least by success-indeed all that is wanted is to get him to realize he really is a success.

4.3.3.4. Last days of the genius & recognition

His health may have deserted him but his passion for mathematics did not diminish in the slightest. Even on his deathbed he continued to play with numbers. It was a touching sight to see him lying in bed solving mathematical problems while his wife fed him rice balls with her own hands. On April 26, 1920, Ramanujan died, aged 32 years, at Chetpet in Madras. Although Ramanujan had taken his notebooks with him to Cambridge, he had no time to delve deep into them. The 600 formulae he jotted down on loose sheets of paper during that one year he had in India after his return from Cambridge, are in the book Lost Note Book brought out by Narosa Publishing House in 1987, on the occasion of Ramanujan's birth centenary. The notebooks were found by George Andrews of Pennsylvania State University in the estate of G.N. Watson in the spring of 1976.

When G. H. Hardy, was asked to rate the top mathematicians of his time on a scale of 100, he gave himself 25 marks, Littlewood got 30, Hillbert got 80, while Ramanujan got 100 upon 100. Such was the reputation that Ramanujan enjoyed among mathematicians of his time. In 1984, over hundred mathematicians and scientists contributed money for a bust sculpted by Paul Granlund, that was later handed over to his wife. Ramanujan left behind 4,000 original theorems, despite his lack of formal education and a short life span.

4.3.4. **Chandrasekhara Venkata Raman(**1888-1970)

He is often remembered as the genius who won the 1930 Nobel Prize for Physics, working with simple equipment barely worth Rs. 300. Chandrasekhara Venkata Raman was one of the greatest experimental physicists of the century and the first Asian scientist to win the Nobel Prize. His spirit of inquiry and devotion to science laid the foundations for scientific research in India, for not only did he win honour as a scientist but also inspired several generations of students.

4.3.4.1. Early Life and Education

Raman was born on November 7,1888, in the town of Tiruchirapalli on the bank of river Cauvery, into a family of traditional agriculturists. It was a departure from family tradition when Raman's father, Chandrasekhara Ayyar, a scholar in physics and mathematics took to teaching in the local school. He loved music. Raman too, grew up in an atmosphere steeped in music, Sanskrit literature and science. His father took another bold decision when he accepted the post of lecturer in physics and mathematics at the A.V.N. College in the harbour town of Vishakhapatnam and moved there with his wife, Parvathi Ammal, and their four-year-old son, Raman. The next ten years of Raman's life were spent in Vishakhapatnam at the high school and in college. He stood first in every class and his genius became evident, early on. He read far beyond his classroom level and when doubts arose, set down questions like 'How' 'Why' and 'Is this true' in the margin of textbooks. After his intermediate examination, he moved to Madras in 1903, and joined the B.A. class in Presidency College. In the year 1905, he was the only student who passed in the first class, also winning a gold medal in physics.

4.3.4.2. Higher Education and Research

In 1907, he took his M.A. degree, again obtaining a first division with a record score of marks. While still a student at the Presidency College, he undertook original investigations in acoustics and optics and also wrote research papers for reputed science journals. The works of the German scientist Helmholtz and the English scientist Lord Rayleigh on acoustics, influenced Raman. When he was eighteen years old, one of his research papers was published in the Philosophical Magazine of England. Later, another paper was published in the scientific journal, Nature. At the age of nineteen, he became a member of the Indian Association for the Cultivation of Science. However, since pursuit of science in India at that time offered little career opportunity, Raman joined the Indian Audit and Accounts Service (I.A.A.S.) standing first in the competitive examination. While he was waiting for the posting to come through he married Lokasundari Ammal on May 6,1907, a girl who proved to be a worthy and life-long companion, and one whose principal interest in life lay in doing all she could to enable to Raman to carry on with his scientific work, uninterrupted. In June 1907, he was posted to Calcutta as Assistant Accountant General in the Finance Department in which he spent the next ten years of his life. Fortunately, a great part of the time was spent in Calcutta, and it was in Calcutta that something happened to give a new turn to his life.

One evening, as Raman was returning from office in a tramcar, he caught sight of the signboard of the Indian Association for the Cultivation of Science (IACS) at 210, Bow Bazaar Street. He got off the tram immediately, and went in. Amritlal Sircar, son of the founder Mahendralal Sircar, was the Honorary Secretary of IACS. Raman walked through spacious rooms and found old scientific instruments, which could still be used for demonstration of experiments. He asked whether he could conduct research there in his spare time. Sircar gladly agreed. Raman moved to a house next door to the Association and a connecting door was opened between his house and the laboratory. During the daytime he attended office but his mornings and nights were devoted to research. The Association thus became his work place for many years.

Raman was transferred to Rangoon, the capital of Burma, in 1909. When his father passed away in 1910, he came to Madras on six months leave. After completing the last rites for his father, he spent the rest of his leave doing research in the Madras University laboratories. Through his link with IACS, Raman had come in contact with Sir Asutosh Mookerjee who, as Vice-Chancellor of Calcutta University, was instrumental in establishing the University Science College in 1915. When Sir Asutosh wanted a professor to fill the newly created Palit Chair in Physics, he could think of none other than Raman and offered him the post. Well aware that the salary would be much lower, Raman quickly gave up his powerful post in the government all the same, and joined the Calcutta University as Palit Professor of Physics in 1917.

In 1919, after the death of Amritlal Sircar, Raman was elected Honorary Secretary of IACS. He now had the charge of two laboratories of the College and of the Association. This gave a new stimulus to his research. Raman frequently referred to this period as the golden era in his career. Absorbed in experiments, it was not unusual for him to forget food and sometimes, working late through the night, he would sleep on one of the laboratory tables. Students came to him from different parts of the country for post-graduate studies and research both at IACS and at the University College. Research workers like Meghnad Saha and S. K. Mitra, who became famous later, worked at these centres. According to the terms of the Palit Chair, he could have kept himself free from teaching work, doing only research. But Raman took immense pleasure in teaching and students were greatly inspired by his lectures. Some of the areas that interested him at that time were, vibrations and sound; theory of musical instruments; optical studies such as diffraction, colours and interference; colloids; molecular scattering of light; X-rays; magnetism and magneto-optics. Raman was a great lover of music and used to say, I should live long, because I have not heard all the music I want to hear. He was a frequent visitor to a musical instruments shop in Balepet, in Bangalore and collected a variety of musical instruments like the mridangam, the tabla, the veena, the violin and the Nagaswaram. Around 1918, he had explained the complex vibrations of the strings of musical instruments. He later defined the characteristic tones emitted by the mridangam, the tabla and so on. Some years later, he was asked to contribute an article on the physics of musical instruments to the Handbuch der Physik and he did so for the eighth volume of that series, published in 1927. Few persons would know that he was elected to the Royal Society, London in recognition of his work on the physics of Indian musical instruments. Raman loved colour, beauty, form, and rhythm in nature. He collected thousands of specimens of butterflies and purchased hundreds of diamonds of different forms.

4.3.4.3. The Raman effect and Nobel

He was so bewitched by the physical properties of the diamond that at one time every researcher in his laboratories was working on the physics of this simplest of all crystal structures. And then came Raman’s discovery of the scattering of light that catapulted him to world fame. The Raman effect, as it is more popularly known, had its origin in the wonderful blue colour of the Mediterranean Sea. Lord Rayleigh had attributed the colour of the sea to the blue of the sky reflected by the water. In 1921, on his way to Oxford to attend the Universities Conference by ship, Raman was struck by the deep blue opalescence of the Mediterranean water. On board the ship itself, he conducted some experiments using a nicol prism. Soon after returning to Calcutta, he carried out more experiments at his IACS Laboratory, with waters collected from different seas. He came to the definite conclusion that it was the scattering of light molecules by the oceanic waters that made them look blue. For the next seven years, Raman and his students carried out several experiments and established the various laws of molecular scattering of light in diverse media and 56 original research papers were published from Raman’s laboratory. Raman finally decided to clinch the issue and asked K. S. Krishnan to take up the experimental work on the anomalous scattering in liquids and vapours, in collaboration with him. While Raman was checking and confirming the results obtained by Krishnan, a joint letter was drafted and sent for publication to Nature on February 16,1928, which was published in its issue of March 31, 1928. On February 28,1928, Raman had announced the discovery to the press and the public. On March 16,1928, Raman delivered an address to the newly formed South Indian Science Association at Bangalore, under the title: A New Radiation. He also acknowledged with affection the assistance given by K.S.Krishnan and K.Venkateshwaran, who were his students. Immediately on return to Calcutta, Raman had this address printed overnight at the Calcutta University Press and mailed the reprints to thousands of scientists all over the world. The phenomenon captured the attention of research workers all over the world. It became famous as the 'Raman Effect'. The spectral lines in the scattered light are now known as 'Raman Lines'.

Investigations, making use of the Raman Effect, began in many countries. During the first twelve years after its discovery, about 1,800 research papers were published on various aspects of it and about 2,500 chemical compounds were studied. The Raman Effect was perceived as one of the greatest discoveries of the third decade of the twentieth century. In 1929, the British Government conferred knighthood on Raman. And finally, in 1930, he was awarded the Nobel Prize in Physics. No Indian or Asian had received the Prize for Physics till then. At the ceremony for the award, Raman used alcohol to demonstrate the Raman Effect but later in the evening, when alcoholic drinks were served at the dinner, Raman did not touch them.

4.3.4.4. Legacy of the legend

Raman left his indelible imprint on several institutes, some of which he had personally helped to set up. In 1933, Raman was appointed Director of the Tata Institute (later renamed Indian Institute of Science) at Bangalore. Under his able guidance and inspiration the Institute soon became famous for the study of crystals. In order to encourage scientific research in India, Raman established the Indian Academy of Sciences in 1934, drawing in distinguished and active scientists from various parts of India as its foundation fellows. The Government of the princely state of Mysore granted 24 acres of land free of cost to promote the activities of the Academy.

His earnest desire was to bring into existence a centre of scientific research worthy of our ancient country, where the keenest intellectuals of our land can probe into the mysteries of the Universe. It led him in 1948 to establish a Research Institute at Hebbal, Bangalore. He gave away all his property to the Institute that later came to be known as the Raman Research Institute. At the Institute, he wished to concentrate on things that interested him and the entrance displayed a board bearing the words, The Institute is not open to visitors. Please do not disturb us.In 1954, Raman was bestowed with the greatest honour the Government of India confers on an Indian-the Bharat Ratna. During the last few years of his life Raman became increasingly isolated from other scientists in India. He was generally critical of the post-Independence scientific efforts in India and disapproved of young scientists leaving India to build their careers. Raman wanted the young persons working with him to take up independent positions and to serve the nation. He saw his laboratory as a centre for training young talent, not a permanent storehouse.

Towards the end, Raman became an Institution in himself and work was all that mattered to him. He never dreamt of a life without work. He had told his doctor, I wish to live a hundred per cent active and fruitful life. Every year he used to deliver a popular science lecture on the occasion of Gandhi Jayanti. On October 2,1970, he spoke on the new theories about hearing and the eardrum. This was his last lecture. After a short illness he passed away on November 21, 1970.

4.3.5. Homi Jehangir Bhabha (1909-1966)

Homi Jehangir Bhabha will always be remembered as the architect of India's nuclear energy programme. One of India's most outstanding scientists and an imaginative administrator with a multifaceted personality, Bhabha was an ardent nationalist.

4.3.5.1. Childhood and Education

Bhabha was born in Bombay on October 30, 1909. His father, Jehangir H. Bhabha, once a student of Oxford University and a reputed advocate, had served Tata Enterprises. Meherbai, Bhabha's mother, was the grand-daughter of Sir Dinshaw Petit, First Baronet, and widely respected in Bombay for his philanthropic endowments. His paternal grandfather was the Inspector-General of education in the State of Mysore.

Bhabha was educated at the Cathedral and John Cannon High School, Elphinstone College and the Royal Institute of Science, Bombay. His parents took a keen interest in nurturing Bhabha's love for science. He had access to his grandfather's large library which contained many books on science. At the age of 15, he had already read Einstein's book on Relativity. Apart from science it was his father's and aunt's collections of music and his grandfather's fine collection of books on painting and art that imbued him with a love for nature and a deep interest in painting, music and literature. His pencil sketches and some of his paintings are preserved in British art galleries. Since his paternal aunt was married to Sir Dorab Tata, as a young boy Bhabha would often go across the road to the ancestral home of J.N.Tata, the founder of the house of Tatas. There he would hear discussions relating to projects for the industrial development of India, ranging from iron and steel to the manufacture of heavy chemicals. All this developed a strong nationalism in him and the resolve to dedicate himself to India's progress and development.

4.3.5.2. Higher Education & Research

Bhabha loved physics and mathematics. But bowing to his father's and Sir Dorab Tata's wishes, who wanted him to become an engineer and join the Tata Iron and Steel Company at Jamshedpur, Bhabha left for Cambridge in 1927 to study engineering. He wanted to change to mathematics but his father promised finance for further studies in mathematics, only if he got a first in engineering. He passed the Mechanical Engineering Tripos in the first class in 1930 and then went on to study theoretical physics as a research scholar. During the two years of his work at the Cavendish Laboratory, Bhabha won several scholarships, travelled across Europe and worked with Pauli in Zurich, Enrico Fermi in Rome and Kramers in Utrecht. His first scientific paper in 1933, dealing with the part played by electron showers in the absorption of gamma radiation won for him the Isaac Newton Fellowship in 1934. Three years later, he was awarded a senior studentship and he continued to work at Cambridge until the Second World War began in 1939. Bhabha came into close contact with famous scientists such as Rutherford, Dirac, Niels Bohr and Heitler and when the discovery of the positron in 1932 opened up a wide field for theoretical physicists, he threw himself into this field of high energy physics. Most of the 50 scientific papers he published were concerned with high-energy physics. In 1937, along with Heitler, he presented the Cascade Theory of Electron Showers which is today known as the 'Bhabha-Heitler Cascade Theory'. The theory explains the process of electron showers in cosmic rays.

4.3.5.3. Path of Nation Building Through Research

Bhabha returned to India in 1939 and accepted the post of Reader at the Indian Institute of Science in 1940. He was in charge of a special cosmic ray research unit set up for him with funding from the Sir Dorab Tata Trust. During the five years of his stay in Bangalore, Bhabha gradually began to be identified with India's great culture. He analyzed the socio-economic problems of the day and was convinced that science was the only means for his country's progress. Bhabha dreamt of the 'great adventure' of building a modern India. In 1941, he was elected a member of the Royal Society and became a Professor in 1942. The University of Cambridge awarded him the Adams Prize. He also received an offer from the Oxford University which he declined, for his heart nursed the desire to build an excellent institution of research in his own homeland. In 1944, Bhabha wrote a letter to the Dorabji Tata Trust in which he said: There is at the moment no big school of research in the fundamental problems of physics. It is absolutely in the interest of India to have a vigorous school of research in fundamental research. When nuclear energy has been successfully applied to power production in, say, a couple of decades from now, India will not have to look abroad for its experts, but will find them ready at hand.

Bhabha's plan was the embryo which was born as a school of physics. The next year, in 1945, the Tata Institute of Fundamental Research (TIFR) was inaugurated in a house in Bombay, the foundation stone of the present building was laid in 1954 and the Institute started functioning in 1962. Today, TIFR is one of the finest research institutions in the world. The great expansion in the Indian economy demanded a steady increase in the country's electricity generating capacity. Bhabha believed that the only way of overcoming power hunger was through the introduction of nuclear power in a phased manner. In 1948, the Atomic Energy Commission was formed and Bhabha was appointed its Chairman. The Commission's responsibilities included: a survey of Indian soils for the materials required for nuclear research, construction of atomic reactors, the purification of atomic materials, conducting fundamental research, and development of training programmes. The Commission utilized the services of scientists at TIFR. Soon the Commission's scope was enlarged and the Atomic Energy Programme began to take shape.

The Department of Atomic Energy thus came into existence as a separate Department of the Government of India in 1954, under the direct control of Prime Minister Nehru. Bhabha became the ex-officio Secretary of the Department. Shortly after the formation of the Department of Atomic Energy, it was decided to create the Atomic Energy Establishment at Trombay for the application of atomic energy to peaceful purposes. While the construction work at Trombay was still in progress, Bhabha spent many sleepless nights and finalized the layout for the campus. He became its first Director in 1957. At a ceremony attended by well known international figures, on January 12, 1967, Prime Minister Indira Gandhi renamed the Trombay Establishment as Bhabha Atomic Research Centre. Bhabha worked to make the country self-reliant in the nuclear field. He stressed that while India needed to draw on the expertise already built up in other countries, her objective must be to exploit her own resources of scientists and technologists as well as the raw materials. With the support and encouragement he got from J. R. D. Tata and Jawaharlal Nehru, Bhabha enjoyed considerable freedom to carry on his work with ease and efficiency. Reactors like Apsara, uranium and zirconium plants, the Van de Graff and cyclotron equipment's were all Bhabha's gifts to the nation.

4.3.5.4. Recognition and Last Days

He was awarded honorary doctorates by several Indian and foreign universities including the University of Cambridge, Padua, Perth, Banaras, Agra, Patna, Lucknow, Allahabad, Andhra and Aligarh. In 1954, the President of India bestowed him the Padma Bhushan honour for his outstanding contributions to nuclear science. In 1955, Bhabha was elected President of the first International Conference on the 'Peaceful Uses of Atomic Energy', organized by the United Nations at Geneva. Bhabha was the first scientist to advocate the peaceful use of atomic energy at international forums. The crowning success of Bhabha's life-long passion came on May 18, 1974 when India conducted its first nuclear explosion for peaceful purposes at Pokhran in Rajasthan. India became the world's sixth nuclear power. However, Bhabha did not live to see his dream prosper further. The Air India Boeing 707 'Kanchenjunga' in which Bhabha was travelling to attend an international conference crashed in a snowstorm on Mont Blanc on January 24, 1966, bringing to a tragic end the life of one of the great scientists of India.

4.3.6. **Dr. Vikram Ambalal Sarabhai(1919-1971**)

Had he so wished, he could have become an industrialist. But Vikram Ambalal Sarabhai's heart was in basic research in mathematics and physics and the interest of his motherland uppermost in his mind in whatever he did. He encouraged students to go abroad for higher studies in the latest areas of Science and Technology but insisted that they return to serve India. He was confident that if the right atmosphere was created for the young scientists to pursue their chosen line of research in India, they would gladly return.

4.3.6.1. Family background, Childhood and Education

The Sarabhais were a famous industrialist family in Ahmedabad. They were also dedicated social workers. When their first daughter, Mridulaben, was just three years old, father Ambalal and mother, Sarala Devi began to think about her education. The Montessori system of education was gaining fame during that time, but there was no school here yet in this system. So, the Sarabhais started a school in their own house with their own eight children. Vikram was born into the Sarabhai household on 12 August 1919. As the children grew, more teachers were employed. At one time, the school had thirteen teachers for the eight children, teachers to teach languages, the sciences, the arts, gardening, and technology. The school also had its own laboratories and workshops.

Vikram showed great earnestness and interest in his studies and was specially enthusiastic about mathematics and science. Vikram came under the influence of many great persons such as Mahatma Gandhi, Rabindranath Tagore, J. Krishna Murthi, Motilal Nehru, V. S. Shrinivasa Shastri, Jawaharlal Nehru, Sarojini Naidu, Maulana Azad, C. F. Andrews, and C. V. Raman etc who stayed with the Sarabhai family whenever they visited Ahmedabad. Vikram loved adventure. As a child he impressed people with the many tricks he could perform with his bicycle. As the bicycle shot forward, he would raise his hands, stretch his legs forward, close his eyes and pedal.

4.3.6.2. Higher Education and Research

After completing his college education, Vikram went to Cambridge University and took his Tripos in Physical Sciences in 1939. Vikram's first love was cosmic rays. Cosmic rays are a stream of energy particles reaching the earth from outer space. On their way to the earth they are influenced by the sun, the atmosphere and the magnetism of the earth. His basic interest was to find out how the rays vary with time and the implications of this phenomenon.

After his return, he did research for a while at the central meteorological station in Poona, and in 1943, he went to the Himalayan peaks in Kashmir to study the intensity of cosmic rays. He was so thrilled that he decided to establish a high altitude research centre. In 1945, when World War II ended, Sarabhai once again went to Cambridge to continue the study of cosmic rays and received his Ph.D. in 1947. Shortly after he returned from Cambridge, he established the Physical Research Laboratory (PRL) at Ahmedabad, an institution devoted to the study of cosmic rays and outer space. Starting with just a few students and laboratory assistants, the group soon developed into a dedicated team of scientists and research workers. Today, it is a premier institution that provides the technology and the scientists needed for the country's space research programme. In spite of his many duties in later years, Sarabhai maintained close contact with PRL all through his life.

In 1955, Sarabhai set up a branch of the Physical Research Laboratory at Gulmarg in Kashmir. Impressed by the work done at this centre, the Atomic Energy Department of the Government of India established a full-fledged High Altitude Research Centre at the same place as the only research centre in the world at such an altitude.

4.3.6.3. Contribution to Space research and Nation Building

Sarabhai will always be remembered as one who ushered in the space age in India by expanding the Indian Space Research Organization (ISRO) which he served as Chairman. He was also responsible for the establishment of the Space Science and Technology Centre at Thumba and the Experimental Satellite Communication Earth Station at Ahmedabad. He established the Rocket Launching Stations at Thumba and Sriharikota. To Sarabhai goes the credit for the many achievements of the Indian space programme during its early years, although he did not live to see the fruits of his labour. Among the projects he planned was the one under which India's first satellite, Aryabhata, was launched in 1975. The groundwork for the Satellite Instructional Television Experiment (SITE) in 1975-76 which sought to bring education to five million people in 2,400 Indian villages, was also done by Sarabhai.

Although he had enormous wealth and rich industrial experience, Vikram Sarabhai was a very modest, soft-spoken and simple man. He looked on all persons as equal and judged each only by the measure of work and responsibility. Sarabhai working in his laboratory at midnight was a common sight and he hated to waste time. Even when waiting to board a plane, he would get together with students in some corner of the airport to discuss work. There was a big pharmaceutical factory of the Sarabhais in Baroda and every Friday he would go there to supervise the work and give instructions. On the train journey from Ahmedabad to Baroda, he would take one or two students to travel with him and discuss their research problems.

In 1947, at the age of 28, he was entrusted the organization of the Ahmedabad Textile Industry Research Association (ATIRA). He had then no experience of textile mills or textile technology. Yet, his intellect and confidence helped him build the institution. In 1956, when the Productivity Congress met in Japan he led the Indian delegation. He was only 37 then. Sarabhai built a number of institutions during his lifetime-and not all of them were scientific institutions. In 1963, he established the Nehru Foundation for Development, for the study of social and educational problems. In 1966, under its auspices, he established the Community Science Centre, whose object was to spread scientific knowledge, to create interest in science and to promote experimentation among students, teachers and the general public. Few may know that it was Sarabhai who established the Indian Institute of Management at Ahmedabad.

4.3.6.4. Legacy and last days

Vikram Sarabhai received several honours for his services to science and society. In 1966 he received the Padma Bhushan. Vikram Sarabhai breathed his last on 31 December 1971 at the young age of 52. After his death, the Government conferred on him the honour of Padma Vibhushan in 1972. The International Astronomical Union named a crater after him on the moon in the Sea of Serenity.

4.3.7. Conclusion

Jagadish Chandra Bose was born on 30 November 1858, in Myemsingh, Faridpur, a part of the Dhaka District now in Bangladesh. He did original scientific work in the area of microwaves, carrying out experiments involving refraction, diffraction and polarization. He developed the use of galena crystals for making receivers, both for short wavelength radio waves and for white and ultraviolet light. Bose established of the Bose Research Institute in Kolkata. It continues to be a famous centre of research in basic sciences. Srinibas Ramanujan was born in Erode, a small village in Tamil Nadu on 22 December 1887, was the greatest among the mathematician of modern world. Chandrasekhara Venkata Raman born in Tamil Nadu on 7 November 1888, made enormous contributions to research in the areas of vibration, sound, musical instruments, ultrasonics, diffraction, photoelectricity, colloidal particles, X-ray diffraction, magnetron, dielectrics, etc. He became the first Asian scientist to be awarded the Nobel Prize for Physics for his discoveries relating to the scattering of light (the Raman Effect). The Government of India conferred upon him its highest award,the Bharat Ratna in 1954.

Homi Bhabha was born on 30 October 1909 in Mumbai. He earned his engineering degree in 1930 and Ph.D. in 1934. He gained international recognition for his excellent work and served as the President of the first United Nations Conference on the Peaceful Uses of Atomic Energy, which was held in Geneva in 1955. He is the pioneer of atomic energy in India. Vikram Sarabhai was born on 12 August 1919 at Ahmedabad. He received higher education in England at St. John's College in 1939. He established the Physical Research Laboratory in Ahmedabad in 1948, in April 1954 and made it the cradle of the Indian Space Programme. Sarabhai pioneered India's space age by expanding the Indian Space Research Organization.

4.3.8. Summary

- *Jagadish Chandra Bose was born on 30 November 1858, in Myemsingh, Faridpur, a part of the Dhaka District now in Bangladesh.*
- *Bose started doing original scientific work in the area of microwaves, carrying out experiments involving refraction, diffraction and polarization. He developed the use of galena crystals for making receivers, both for short wavelength radio waves and for white and ultraviolet light.*
- *Bose established of the Bose Research Institute in Kolkata. It continues to be a famous centre of research in basic sciences.*
- *Ramanujan was born in Erode, a small village in Tamil Nadu on 22 December 1887.*
- *He went to Cambridge and worked with G. H. Hardy in Cambridge. Ramanujan made outstanding contributions to analytical number theory, elliptic functions, continued fractions, and infinite series. His published and unpublished works have kept some of the best mathematical brains in the world busy to this day.*
- *Chandrasekhara Venkata Raman was born at Tiruchirapalli in Tamil Nadu on 7 November 1888.*
- *He made enormous contributions to research in the areas of vibration, sound, musical instruments, ultrasonics, diffraction, photoelectricity, colloidal particles, X-ray diffraction, magnetron, dielectrics, etc.*
- *He was knighted in 1929, and in 1930, became the first Asian scientist to be awarded the Nobel Prize for Physics for his discoveries relating to the scattering of light (the Raman Effect). The Government of India conferred upon him its highest award,the Bharat Ratna in 1954.*

- *Homi Bhabha was born on 30 October 1909 in Mumbai. He earned his engineering degree in 1930 and Ph.D. in 1934. In 1937, together with W. Heitler, a German physicist, Bhabha solved the riddle about cosmic rays.*
- *In 1948, Homi Bhabha was appointed the Chairman of the International Atomic Energy Commission. He gained international recognition for his excellent work and served as the President of the first United Nations Conference on the Peaceful Uses of Atomic Energy, which was held in Geneva in 1955. He is the pioneer of atomic energy in India.*
- *Vikram Sarabhai was born on 12 August 1919 at Ahmedabad. He received higher education in England at St. John's College in 1939.*
- *He established the Physical Research Laboratory in Ahmedabad in 1948, in April 1954, PRL moved into a new building and Dr. Sarabhai made it the cradle of the Indian Space Programme.*
- *Sarabhai pioneered India's space age by expanding the Indian Space Research Organization.*
- *He was the recipient of the Bhatnagar Memorial Award for Physics in 1962, the Padma Bhushan in 1966, and was posthumously awarded the Padma Vibhushan.*

4.3.9. Exercise

- Write an essay on the life and career of Jagadish Chandra Bose.
- Give an account on the biography and discovery of Srinibas Ramanujan in the filed of Mathematics.
- Discuss the early life and scientific discovery of C.V.Raman in the sphere of physical science.
- Narrate the life and contribution of Homi Jahangir Bhaba for the nuclear research in India.
- Assess the contribution of Bikram Sarabhai for the space research in India.

4.3.10. Further Readings

- R. Parthasarathy, Paths of Innovators In Science, Engineering and Technology, EastWest Books (Madras) Pvt. Ltd, 2000.
- Glimpses of India's Statistical Heritage, Edited by: J.K. Ghosh, S.K. Mitra, K.R. Parthasarathy, Wiley Eastern Limited, 1992.
- Jagjit Singh, Some Eminent Indian Scientists, Publications Division, Ministry of Information and Broadcasting, Government of India, 1991.
- B.C. Berndt and R.A. Rankin, Ramanujan: Essays and Surveys, Hindustan Book Agency, 2003.
- Robert Kanigel, The Man Who Knew Infinity, A Life of the Genius Ramanujan, Rupa & Co., 1992.
- S.R. Ranganathan, Ramanujan: The Man and the Mathematician, London, 1967.
- Subrata Dasgupta, Jagadish Chandra Bose and the Indian Response to Western Science, Oxford University Press, 1999.
- Chintamani Deshmukh, Homi Jehangir Bhabha, National Book Trust, India, 2003.
- G. Venkataraman, Bhabha and his Magnificent Obsessions, Universities Press, 1994.
- G. Venkataraman, Raman and His Effect, Universities Press, 1995.

****

The End