THE INDIAN TRADITION IN SCIENCE AND TECHNOLOGY: AN OVERVIEW[1]

Any study of the Indian tradition of science has to start with linguistics. This is so not only because linguistics is the earliest of Indian sciences to have been rigorously systematised, but also because this systematisation became the paradigm example for all other sciences.

Like all sciences and arts of India, Linguistics finds its first expression in the Vedas. For most of the Indian sciences, the elements of study and the categories of analysis were established in the vaidika period, and the basic data was collected and preliminary systematisation achieved already at that stage. Thus, for the science of linguistics, we find, in the śikṣā and prātiśakhya texts associated with the various Vedas, a complete and settled list of phonemes appropriately classified into vowels, semi-vowels, sibilants and the five groups of five consonants, all arranged according to the place of articulation that moves systematically from the throat to the lips. Phonetics and phonology are therefore taken for granted by all post-vaidika authorities on etymology (nirukta*)* and grammar (vyākaraṇa), including Yāska and Pāṇini. In the prātiśakhya literature we also find the morpho-phonemic (sandhi) rules and much of the methodology basic to the later grammatical literature.

Indian Linguistics finds its rigorous systematisation in Pāṇini's *Aṣṭādhyāyī*. The date of this text, like that of much of the early Indian literature, is yet to be settled with certainty. But it is not later than 500 BC. In *Aṣṭādhyāyī*, Pāṇini achieves a complete characterisation of the Sanskrit language as spoken at his time, and also specifies the way it deviated from the Sanskrit of the Vedas. Using the sūtras of Pāṇini, and a list of the root words of the Sanskrit language (dhātupāṭha), it is possible to generate all possible valid utterances in Sanskrit. This is of course the main thrust of the generative grammars of today that seek to achieve a grammatical description of language through a formalised set of derivational strings. In fact, till the Western scholars began studying generative grammars in the recent past, they failed to understand the significance of *Aṣṭādhyāyī*: till then Pāṇinian sūtras for them were merely artificial and abstruse formulations with little content.

Patañjali (circa first century BC) in his elaborate commentary on *Aṣṭādhyāyī, Mahābhāṣya,* explains the rationale for the Pāṇinian exercise. According to *Mahābhāṣya*, the purpose of grammar is to give an exposition of all valid utterances. An obvious way to do this is to enumerate all valid utterances individually. This is how the celestial teacher Bṛhaspati would have taught the science of language to the celestial student, Indra. However for ordinary mortals, not having access to celestial intelligence and time, such complete enumeration is of little use. Therefore, it is necessary to lay down widely applicable general rules (utsarga sūtras) so that with a comparatively small effort men can learn larger and larger collections of valid

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utterances. What fails to fit in this set of general rules should, according to the *Mahābhāṣya*, then be encompassed in exceptional rules (apavāda sūtras), and so on.

In thus characterising grammar, Patañjali expounds perhaps the most essential feature of the Indian scientific effort. Science in India starts with the assumption that truth resides in the real world with all its diversity and complexity. For the linguist, what is ultimately true is the language as spoken by the people in all their diverse expressions. As Patañjali emphasises, valid utterances are not manufactured by the linguist, but are already established by the practice in the world. One does not go to a linguist asking for valid utterances, the way one goes to a potter asking for pots. Linguists make generalisations about the language as spoken in the world. These generalisations are not the truth behind or above the reality of the spoken language. These are not idealisations according to which reality is to be tailored. On the other hand what is true is what is actually spoken in the real world, and some part of the truth always escapes our idealisation of it. There are always exceptions. It is the business of the scientist to formulate these generalisations, but also at the same time to be always attuned to the reality, to always be conscious of the exceptional nature of each specific instance. This attitude, as we shall have occasion to see, permeates all Indian science and makes it an exercise quite different from the scientific enterprise of the West.

In linguistics, after the period of *Mahābhāṣya*, grammarians tried to provide continuous refinements and simplifications of Pāṇini. A number of Sanskrit grammars were written. One of them, *Siddhānta Kaumudī* (c.1600) became eminently successful, perhaps because of its simplicity. These attempts continued till the 19th century. Another form of study that became popular amongst the grammarians was what may be called philosophical semantics, where grammarians tried to fix and characterise the meaning of an utterance by analysing it into its basic grammatical components. This, of course, is the major application for which grammar is intended in the first place.

Grammars for other Indian languages were written, using Pāṇinian framework as the basis. These grammars were not fully formalised in the sense of Pāṇini. Instead, they started with the Pāṇinian apparatus and specified the transfer rules from Sanskrit and the specific morpho-phonemic rules (sandhi rules) for the language under consideration. Such grammars for various Prakrit languages of the North and also the South Indian languages continued to be written until the 18th century. In the 16th century Kṛṣṇadāsa even wrote a grammar for the Persian language, *Pārasī Prakāśa*, styled on the grammars of the Prakrit language.

II

Among the sciences of the Indian tradition Astronomy and Mathematics occupy an important place. Indian mathematics finds its early beginnings in the famous *Śulva Sūtras* of the vaidika times. Written to facilitate the accurate construction of various types of sacrificial altars for the vaidika ritual, these sūtras lay down the basic geometrical properties of plane figures like the triangle, the rectangle, the rhombus, and the circle. Basic categories of the Indian astronomical tradition were similarly established in the various *Vedāṅga Jyotiṣa* texts.

Rigorous systematisation of India astronomy begins with Āryabhaṭa (b.476 AD). His *Āryabhaṭīya* is a concise text of 121 aphoristic verses containing separate sections on the basic astronomical definitions and parameters; basic mathematical procedures in arithmetic, geometry, algebra and trigonometry; methods of determining mean and true positions of the planets at any given time; and description of the motion of Sun, Moon and the planets along with computation of the solar and lunar eclipses. Āryabhaṭa was followed by a long series of illustrious astronomers. Some of the well known names are those of Varāhamihira (d.578 AD), Brahmagupta (b.598 AD), Bhāskara I (c.629 AD), Lalla (c. 8th C AD), Muñjāla (932 AD), Śrīpati (c.1039 AD), Bhāskara II (b.1114 D), Mādhava (c.14th C AD), Parameśvara (c.15th C AD), Nīlakaṇṭha (c. 16th C AD), Jyeṣṭhadeva (c.16th C AD), Acyuta Piṣāraṭi (c.16th C AD) Gaṇeśa Daivajña (c.16th C AD), Kamalākara (c. 17th C AD), Munīśvara (c. 17th C AD), Putumana Somayājī (c. 17th C AD), Jagannāha Paṇḍita (c. 18th C AD) and several others. The texts of several of these astronomers gave rise to a host of commentaries and refinements by later astronomers and became the cornerstones of flourishing schools of astronomy and mathematics. The tradition continued to thrive up to the late eighteenth century. In Kerala and Orissa original astronomical works continued to be written till much later.

The most striking feature of this long tradition of Indian mathematics and astronomy is the efficacy with which complex mathematical problems were handled and solved. The basic theorems of plane geometry had already been discovered in *Śulva Sūtras*. By the time of *Āryabhaṭīya* (c.499), a sophisticated theory of numbers including the concepts of zero, and negative numbers had also been established and simple algorithms for arithmetical operations had been formulated using the place-value notation. By then, the Indian tradition of mathematics was aware of all the basic mathematical concepts and procedures that are today taught at the high school level. By the 9th or 10th century sophisticated problems in algebra, such as quadratic indeterminate equations, were solved. By the 14th century, infinite series for trigonometric functions like sine and cosine were written down. By the same time, irrational character of π was recognised, and its value was determined to very high levels of approximation.

The reason for this spectacular success of the Indian mathematicians probably lies in the explicitly algorithmic and computational nature of Indian mathematics. Indian mathematicians were not trying to discover the ultimate axiomatic truths in mathematics; they were interested in finding methods of solving specific problems that arose in the astronomical and other contexts. Therefore, Indian mathematicians were prepared to work with simple algorithms that may give only approximate solutions to the problem at hand, and to evolve theories of error and recursive procedures so that the approximations may be kept in check. This algorithmic methodology persisted in the Indian mathematical consciousness till recently.

Srinivasa Ramanujan in the twentieth century seems to have made his impressive mathematical discoveries through the use of this traditional Indian methodology.

Similar pragmatic concerns, of determining time and calculating the positions of the various planets and eclipses of the Sun and the Moon reasonably accurately, informed the efforts of the Indian astronomers. In this they were eminently successful. In their calculations Indian astronomers often take the beginning of the Kaliyuga in 3102 BC as their starting point. The siddhānta texts deal with a much larger period consisting of 43,20,000 years called a Mahāyuga or sometimes even a period 1000 times greater, called a Kalpa. While working with such long time periods, the Indian astronomers were able to keep their techniques fairly simple and their parameters well refined at all times. Even towards the end of the eighteenth century and early parts of nineteenth, when the active astronomical tradition had become dormant in large parts of India, European astronomers were able to locate Brahmins in South India, who could calculate details of the current eclipses to an accuracy comparable to, and often better than the best calculations of Europe of the time.

The reasons for the simplicity and accuracy of the Indian astronomical techniques are again to be found in the pragmatic attitude of the Indians towards the sciences. The Indian astronomers were in the business to calculate and to compute, not to form pictures of the heavens as they ought to be in reality. Indian astronomers do use some geometrical models, but for them these are no more than artefacts in their calculations. It is obvious that the astronomical parameters obtained in such a pragmatic approach will get out of tune with reality sooner or later and the calculated positions of the planets will start deviating from actual. Indian astronomers are aware of this and were quite willing to take up the onerous task of continuously observing the skies, continuously checking their computations against observations and repeatedly re-adjusting their parameters so as to make their calculations accord with reality. Thus the sixteenth century astronomer Nīlakaṇṭha Somasutvan, finding a contemporary commentator lamenting about the different times given in different siddhāntas and the computed times differing from the actual ones, exhorts:

> O faint-hearted, there is nothing to be despaired of - One has to realise that five siddhāntas had been correct at a particular time. Therefore one has to search for a siddhānta that does not show discord with the actual observation at the present time. Such accordance has to be ascertained by observers during times of eclipses, etc. When siddhāntas show discord observations should be made with the use of instruments and correct number of revolutions etc. found, and a new siddhānta enunciated.

A little later Jyeṣṭhadeva in his *Dṛkkaraṇa* tells us how from Āryabhaṭa to the present day the astronomers have adjusted the parameters to accord with observations and how he too is doing the same job for his times. He ends with the advice that 'henceforth too the deviations that occur should be carefully observed and revisions effected'.

III

The third major science of the classical tradition is Āyurveda*,* the science of life. Like linguistics and astronomy, Āyurveda too finds its early expression in the Vedas, especially the *Atharvaveda*, in which much early medicinal knowledge of India is recorded. Systematisation of Āyurveda took place between 5th century BC to 5th century AD. *Caraka Saṃhitā, Suśruta Saṃhitā* and *Aṣṭāṅga Saṃgraha,* the so called *Bṛhattrayī* texts were compiled in this period. These are complete compendiums of Āyurvedic theory and practice, and remain relevant and popular even today. The *Bṛhattrayī* period was followed by a long period of intense activity directed at refining the theory and practice of medicine, and bringing more and more information into the stream of systematic medicine. This process of accretion of information and refinement of practice continued up to the beginning of the nineteenth century.

Like in linguistics and astronomy, the remarkable feature of Indian tradition of medicine is its pragmatic attitude towards scientific theorisation. The Āyurvedic texts provide a theoretical framework through which the problem of finding an appropriate cure for a particular patient must be approached. However, the texts never tire of reminding the practitioner that he must never be guided by mere theoretical considerations, and therefore he must be constantly observant of all the specific features that a particular case presents. For C*araka Saṃhitā* the most desirable intellectual accomplishment of a doctor is that of possessing yukti, which is defined as the capacity of the trained intellect to see the course of action through the complexity of phenomena with their multiple causes.

The attitude of Āyurveda towards theoretical generalisations is brought out in a revealing verse of *Suśruta Saṃhitā*. While defining the theoretical categories through which the medicinal properties of a substance are to be determined, the text warns that the wise physician should never raise theoretical arguments about the properties of a drug when they are already known and established in tradition based on actual practice, because after all 'a thousand reasons will not make the drugs of the ambaṣṭha group perform laxative functions'. This attitude towards theory gives the Āyurvedic texts a refreshing openness and a surprising keenness of observation. Nothing that may have any effect on the problem of health seems to escape the observation of the physicians. One finds the physicians worrying about differing aspects of the seasons, the soils, the waters and so on. And in the therapeutic sections they bring together all their theoretical understanding along with all the folk practices that have been proved to be efficacious in tradition.

This pragmatic attitude towards scientific theorisation made the doing of science in India a rather painstaking business. The Indian scientists, not having the luxury of reducing the reality of the world to that encompassed by their theories of the time, had to be continuously aware of the world in its complete complexity, and had to continuously refine and simplify their procedures in order to operate successfully within the complexity of the world.

That they were able to do this systematically in a number of fields over a long period of more than 2000 years is a measure of their ingenuity and industry. One can only marvel at the stupendousness of the task of encapsulating the whole of Sanskrit language as it was spoken in 4000 aphoristic rules. Equally remarkable are the efforts of the astronomer-mathematicians of repeatedly refining their parameters to fit the observations, so that ever since Āryabhaṭa the Indians always had access to reasonably accurate information about the motions of the heavens. But the astronomer-mathematicians also simplified their computations to an extent that learned Brahmins in their innumerable locales could also compute all the astronomical information that mattered to the residents. The effort of Indian physicians falls in the same class. They were not only able to painstakingly acquire and systematise within their theoretical framework all the information about drugs and diseases that was current amongst the people in diverse areas, but were also able to simplify their theories sufficiently so that much of the Āyurvedic science became the folklore of health known in all families. The fact that the Indian scientists given their theoretical attitude had to be necessarily open to the world around them perhaps ensured that the folk and the science continued to remain in a symbiotic relation with each other.

Besides linguistics, astronomy and mathematics, and medicine, Indians also developed the sciences of matter (Padārthaśāstra), metallurgy (Rasaśāstra), architecture (Vāstuśāstra), music (Saṅgītaśāstra) etc. To all of these sciences they brought their peculiarly Indian mode of careful but tentative generalisation and continuous keen observation.

IV

The pragmatic attitude of conceptual sophistication and operational simplicity that we have noticed amongst the sciences of India also informed Indian technologies. A systematic history of the traditional Indian technologies is yet to be written. Therefore one has to rely largely on the accounts of European travellers and administrators who observed the Indian practices and wrote about them during the early phase of European conquest of India.

The major technological endeavour of India was of course in the field of agriculture. Col. Alexander Walker writing in the early nineteenth century was amazed at the keen interest that ordinary Indians showed in everything connected with agriculture. He was also greatly impressed by the care with which Indian cultivators tended their fields. To him the fields of Malabar and Gujarat looked like carefully laid out gardens. This care was coupled with an intimate knowledge of the soils, the seasons and seeds The Indian cultivators had mastered the techniques of rotation of crops, irrigation, manuring, and selection of seeds etc., from very early times. These techniques had been so well studied and so optimised to the peculiar conditions of each area that John Voelcker, Consulting Chemist to the Royal Agricultural society, sent to India towards the end of the nineteenth century to suggest ways of improving Indian agriculture through the use of chemistry could recommend little by way of technological change. He was of the opinion that if only the traditional facilities of water and manure could be ensured, the farmers of India could obtain the best possible yields. As for suggesting improvements he felt that it was much easier to propose improvements in English agriculture, than to make really valuable suggestions for that of India. Another expert of early twentieth century, John Kenny, remarked in the same vein that he did not consider it wise 'to suggest seed selection in a land where 4000 different sorts of paddy are grown in one province alone and carefully differentiated according to their qualities and land suitable for them'.

The implements of the Indian cultivator often seemed rough and primitive to the occasional observer. However it was soon realised that these implements were fully adapted to the particular conditions in which they operated and even in the late nineteenth century nothing could be suggested by way of their improvement. An early experiment during the later half of the eighteenth century to introduce the heavy English plough near Salsette on the West coast proved a disaster. In 1795, Cap. Thos Holcott reported on the sophistication of the Indian drill plough widely used in the Andhra region. The drill plough till then was considered a ômodernö European invention.

With their simple but sophisticated implements and their meticulous techniques of agriculture, the Indian farmers were able to obtain impressive yields. It was reported that in early nineteenth century the produce of an acre of land in the Allahabad region amounted to over 55 Bushels of wheat per harvest while that in England around the same time was only about 20 Bushels. Since the Indian farmer in this region usually produced two crops a year, the annual yield of each acre was over 110 Bushels at this time. The productivity of Indian agriculture, however, declined very rapidly during the nineteenth century. But even in the 1890's lands which had access to irrigation and manure yielded harvests comparable to those in England, and larger than the harvests obtained those days in Europe, USA and Australia.

V

The Indian technical ingenuity in evolving simple techniques that are sophisticated enough to take advantage of the full complexity of the local situation, and meshing these locally adapted techniques into impressively large systems can be best seen in the tank irrigation system of South India. The whole of South India was dotted with these tanks. A British expert writing in the 1850's estimated the total number of such tanks in the Madras Presidency to be over 50,000. Another estimate indicated that in the eighteenth century there were more than 38,000 tanks in the region which later constituted the Mysore State. The state had an area of around 29,000 square miles. It is, therefore, a fair estimate that there were over a lakh tanks in the whole of South India. These tanks were constructed and maintained by local effort. Together they formed a closely knit whole so that the outflow from the one at a higher level supplied the one at a lower level, and so on. This chain of tanks was so complete and interrelated within itself that British engineers of the nineteenth century felt that it would have been impossible to add another tank to the chain.

The Indian genius for performing vast tasks through simple, small and dispersed techniques is seen even better in the case of metallurgy. Early European observes noticed the Indians using small furnaces for smelting and refining iron and making steel. Scores of seventeenth, eighteenth and early nineteenth century accounts of Indian manufacture of iron and steel are available, and these pertain to perhaps a hundred districts spread all over India. The smelting furnaces described in these accounts were of quite rough construction from the outside. However, the observers noticed that the internal proportions and various angles needed to be rather exact, and there were cases where the furnace had to be demolished and reconstructed to correct some minor error in the angle of blast, or in some internal proportion. Yet these sophisticated furnaces were routinely constructed by the Indian iron-smiths in a matter of hours without the help of any complicated instruments.

These furnaces worked quite efficiently by the standard of those times. According to one detailed account, two units of charcoal were sufficient to produce one unit of crude iron in these furnaces. Processes of refining iron and steel making were also equally efficient. Steel was prepared by direct carbonisation of iron in closed crucibles in which green leaves, wood and charcoal were all put together. This process seemed mysterious to the British observes, since a process of direct conversion was discovered in Europe only in the 1820's. Even then, observers were often surprised at the quickness with which steel was made in the Indian furnaces, the process taking a few hours compared to many days taken in the corresponding European processes.

The simplicity of these Indian techniques should be seen in the context of the fact that Indian iron and steel had been renowned for their qualities for centuries past. All over India, one can find scattered iron pillars and girders of very high quality, especially as regards corrosion resistance. Indian steel has an equally distinguished record of maintaining excellent quality, and even in the late eighteenth century an expert in Britain when presented with a sample of Indian steel noted that it was 'excellently adapted for the purpose of fine cutlery, and particularly for all edged instruments used for surgical purposes'.

With these small and dispersed furnaces which produced perhaps half a ton of iron during a week's operation, India produced large amount of iron and steel. According to some nineteenth century enumerations there were hundreds of such furnaces operating in certain districts and taluks. On the basis of this information it has been estimated the total number of such furnaces in India towards the latter half of the eighteenth century could have been over 10,000 and these furnaces together had the potential to produce some 2 lakh tonnes of iron annually.

VI

A survey of Indian technologies cannot be complete without some discussion of textiles, the great industrial enterprise of pre-British India. Up to 1800 India was the world's leading producer and exporter of textiles. This production was almost entirely based on techniques that could be operated at the level of the individual or the family. Spinning of yarn was an activity in which perhaps whole of India participated. According to an observer from Manchester, Amo Pearse, who in 1930 visited India to study its cotton industry, there were probably 5 crore spinning wheels (charkhas) intermittently at work even then. And this simple small wheel was so efficient that till the early decades of the nineteenth century a widowed mother could still maintain a whole family in reasonable manner by spinning on the charkha for a few hours a day. Weaving was a relatively more specialised activity. However, the number of those belonging to the weaver castes was smaller in comparison only to those from the cultivating castes. Early nineteenth century data for certain districts of South India indicate that each district had around 20,000 looms. Arrno Pearse in 1930 estimated the number of handlooms operating in India to be in the vicinity of 20 lakhs.

There were vast regions of India which specialised in specific types of fabrics. Each of these areas developed techniques of weaving, bleaching, dyeing and painting etc., which were indigenous to the region, and also had its own characteristic designs, motifs and symbols. For example, in Western India alone, Sironj in Rajasthan and Burhanpur in Khandesh were major centres of cotton painting; cheap printed cottons came from Ahmedabad; woollens including the extra-ordinary Cashmere Shawls were produced in Kashmir; true silks were worked as patolas at Patan in Gajarat and so on.

These dispersed and diverse techniques were so optimised that textile produced in Britain through the technologies of industrial revolution could hardly match the Indian textiles in quality or price. Till the early nineteenth century, mill produced fabric had to be protected from Indian competition by the imposition of duties of 70 to 80 per cent on the cottons and silks imported from India, or by positive prohibition. The historian H. H. Wilson noted that without such prohibitory duties and decrees, ‘the mills of Paisley and Manchester would have been stopped in their outset and could scarcely, have been again set in motion even by the power of steam’.

The Indians had developed efficient locality-specific techniques not only in agriculture, irrigation, metallurgy and textiles, but also in diverse other areas like building and construction, sculpture, pottery, making of glass, and even in luxuries like making of ice etc. Most historians of pre-British India are agreed that India of that time was not only an agricultural, but also an industrial society.