Science in Ancient India

Subhash C. Kak
Louisiana State University
Baton Rouge, LA 70803-5901, USA

November 15, 2005

In *Ananya: A portrait of India*, S.R. Sridhar and N.K. Mattoo (eds.). AIA: New York, 1997, pages 399-420

1

'Veda' means knowledge. Since we call our earliest period Vedic, this is suggestive of the importance of knowledge and science, as a means of acquiring that knowledge, to that period of Indian history. For quite some time scholars believed that this knowledge amounted to no more than speculations regarding the self; this is what we are still told in some schoolbook accounts. New insights in archaeology, astronomy, history of science and Vedic scholarship have shown that such a view is wrong. We now know that Vedic knowledge embraced physics, mathematics, astronomy, logic, cognition and other disciplines. We find that Vedic science is the earliest science that has come down to us. This has significant implications in our understanding of the history of ideas and the evolution of early civilizations.

The reconstructions of our earliest science are based not only on the Vedas but also on their appendicies called the Vedangas. The six Vedangas deal with: *kalpa*, performance of ritual with its basis of geometry, mathematics and calendrics; *shiksha*, phonetics; *chhandas*, metrical structures; *nirukta*, etymology; *vyakarana*, grammar; and *jyotisha*, astronomy and other cyclical phenomena. Then there are naturalistic descriptions in the various Vedic books that tell us a lot about scientific ideas of those times.

Briefly, the Vedic texts present a tripartite and recursive world view. The universe is viewed as three regions of earth, space, and sky with the corresponding entities of Agni, Indra, and Vishve Devah (all gods). Counting separately the joining regions leads to a total of five categories where, as we see in Figure 1, water separates earth and fire, and air separates fire and ether.

In Vedic ritual the three regions are assigned different fire altars. Furthermore, the five categories are represented in terms of altars of five layers. The great altars were built of a thousand bricks to a variety of dimensions. The discovery that the details of the altar constructions code astronomical knowledge is a fascinating chapter in the history of astronomy (Kak 1994a; 1995a,b).

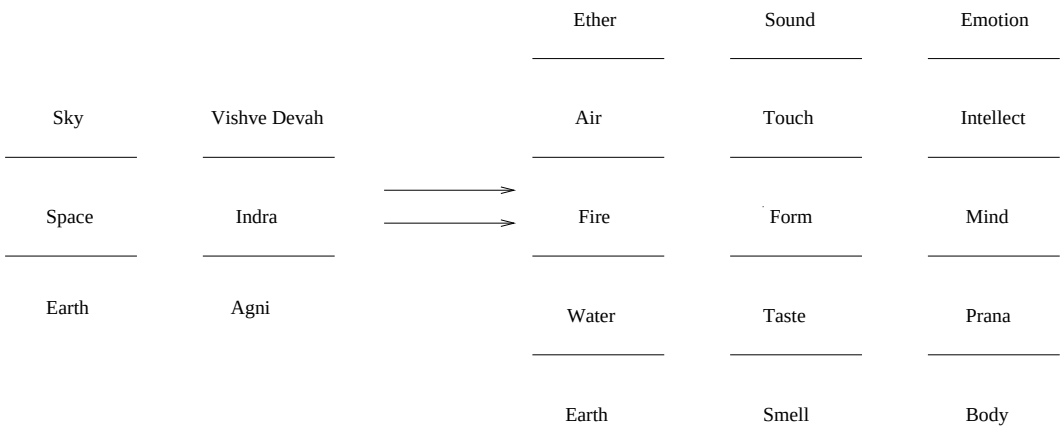

Figure 1: From the tripartite model to five categories of analysis

In the Vedic world view, the processes in the sky, on earth, and within the mind are taken to be connected. The Vedic rishis were aware that all descriptions of the universe lead to logical paradox. The one category transcending all oppositions was termed *brahman*. Understanding the nature of consciousness was of paramount importance in this view but this did not mean that other sciences were ignored. Vedic ritual was a symbolic retelling of this world view.

Chronology

To place Vedic science in context it is necessary to have a proper understanding of the chronology of the Vedic literature. There are astronomical references in the Vedas which recall events in the third or the fourth millennium B.C.E. and earlier. The recent discovery (e.g. Feuerstein 1995) that Sarasvati, the preeminent river of the Rigvedic times, went dry around 1900 B.C.E. due to tectonic upheavels implies that the Rigveda is to be dated prior to this epoch, perhaps prior to 2000 B.C.E. since the literature that immediately followed the Rigveda does not speak of any geological catastrophe. But we cannot be very precise about our estimates. There exist traditional accounts in the Puranas that assign greater antiquity to the Rigveda: for example, the Kaliyuga tradition speaks of 3100 B.C.E. and the Varāhamihira tradition mentions 2400 B.C.E. According to Henri-Paul Francfort (1992) of the Indo-French team that surveyed this area, the Sarasvati river had ceased to be a perennial river by the third millennium B.C.E.; this supports those who argue for the older dates. But in the absence of conclusive evidence, it is prudent to take the most conservative of these dates, namely 2000 B.C.E. as the latest period to be associated with the Rigveda.

The textbook accounts of the past century or so were based on the now disproven supposition that the Rigveda is to be dated to about 1500-1000 B.C.E. and, therefore, the question of the dates assigned to the Brahmanas, Sutras and other literature remains open. The detailed chronology of the literature that followed Rigveda has not yet been worked out. A chronology of this literature was attempted based solely on the internal astronomical

evidence in the important book "Ancient Indian Chronology" by the historian of science P.C. Sengupta in 1947. Although Sengupta's dates have the virtue of inner consistency, they have neither been examined carefully by other scholars nor checked against archaeological evidence.

This means that we can only speak in the most generalities regarding the chronology of the texts: assign Rigveda to the third millennium B.C.E. and earlier and the Brahmanas to the second millennium. This also implies that the archaeological finds of the Indus-Sarasvati period, which are coeval with Rigveda literature, can be used to cross-check textual evidence.

No comprehensive studies of ancient Indian science exist. The textbook accounts like the one to be found in Basham's "The Wonder that was India" are hopelessly out of date. But there are some excellent surveys of selected material. The task of putting it all together into a comprehensive whole will be a major task for historians of science.

This essay presents an assortment of topics from ancient Indian science. We begin with an outline of the models used in the Vedic cognitive science; these models parallel those used in ancient Indian physics. We also review mathematics, astronomy, grammar, logic and medicine.

1 Vedic cognitive science

The Rigveda speaks of cosmic order. It is assumed that there exist equivalences of various kinds between the outer and the inner worlds. It is these connections that make it possible for our minds to comprehend the universe. It is noteworthy that the analytical methods are used both in the examination of the outer world as well as the inner world. This allowed the Vedic rishis to place in sharp focus paradoxical aspects of analytical knowledge. Such paradoxes have become only too familiar to the contemporary scientist in all branches of inquiry (Kak 1986).

In the Vedic view, the complementary nature of the mind and the outer world, is of fundamental significance. Knowledge is classified in two ways: the lower or dual; and the higher or unified. What this means is that knowledge is superficially dual and paradoxical but at a deeper level it has a unity. The Vedic view claims that the material and the conscious are aspects of the same transcendental reality.

The idea of complementarity was at the basis of the systematization of Indian philosophic traditions as well, so that complementary approaches were paired together. We have the groups of: logic (nyaya) and physics (vaisheshika), cosmology (sankhya) and psychology (yoga), and language (mimamsa) and reality (vedanta). Although these philosophical schools were formalized in the post-Vedic age, we find an echo of these ideas in the Vedic texts.

In the Rigveda there is reference to the yoking of the horses to the chariot of Indra, Ashvins, or Agni; and we are told elsewhere that these gods represent the essential mind. The same metaphor of the chariot for a person is encountered in Katha Upanishad and the Bhagavad Gita; this chariot is pulled in different directions by the horses, representing senses, which are yoked to it. The mind is the driver who holds the reins to these horses; but next to the mind sits the true observer, the self, who represents a universal unity. Without this self no coherent behaviour is possible.

The Five Levels

In the Taittiriya Upanishad, the individual is represented in terms of five different sheaths or levels that enclose the individual's self. These levels, shown in an ascending order, are:

- The physical body (annamaya kosha)
- Energy sheath (pranamaya kosha)
- Mental sheath (manomaya kosha)
- Intellect sheath (vijnanamaya kosha)
- Emotion sheath (anandamaya kosha)

These sheaths are defined at increasingly finer levels. At the highest level, above the emotion sheath, is the self. It is significant that emotion is placed higher than the intellect. This is a recognition of the fact that eventually meaning is communicated by associations which are influenced by the emotional state.

The energy that underlies physical and mental processes is called prana. One may look at an individual in three different levels. At the lowest level is the physical body, at the next higher level is the energy systems at work, and at the next higher level are the thoughts. Since the three levels are interrelated, the energy situation may be changed by inputs either at the physical level or at the mental level. When the energy state is agitated and restless, it is characterized by *rajas*; when it is dull and lethargic, it is characterized by *tamas*; the state of equilibrium and balance is termed *sattva*.

The key notion is that each higher level represents characteristics that are emergent on the ground of the previous level. In this theory mind is an emergent entity, but this emergence requires the presence of the self.

The Structure of the Mind

The Sankhya system takes the mind as consisting of five components: manas, ahankara, chitta, buddhi, and atman. Again these categories parallel those of Figure 1.

Manas is the lower mind which collects sense impressions. Its perceptions shift from moment to moment. This sensory-motor mind obtains its inputs from the senses of hearing, touch, sight, taste, and smell. Each of these senses may be taken to be governed by a separate agent.

Ahankara is the sense of I-ness that associates some perceptions to a subjective and personal experience.

Once sensory impressions have been related to I-ness by ahankara, their evaluation and resulting decisions are arrived at by buddhi, the intellect. Manas, ahankara, and buddhi are collectively called the internal instruments of the mind.

Next we come to chitta, which is the memory bank of the mind. These memories constitute the foundation on which the rest of the mind operates. But chitta is not merely a passive instrument. The organization of the new impressions throws up instinctual or primitive urges which creates different emotional states.

This mental complex surrounds the innermost aspect of consciousness which is called atman, the self, brahman, or jiva. Atman is considered to be beyond a finite enumeration of categories.

All this amounts to a brilliant analysis of the individual. The traditions of yoga and tantra have been based on such analysis. No wonder, this model has continued to inspire people around the world to this day.

2 Mathematical and physical sciences

Here we review some new findings related to the early period of Indian science which show that the outer world was not ignored at the expense of the inner.

Geometry and mathematics

Seidenberg, by examining the evidence in the Shatapatha Brahmana, showed that Indian geometry predates Greek geometry by centuries. Seidenberg argues that the birth of geometry and mathematics had a ritual origin. For example, the earth was represented by a circular altar and the heavens were represented by a square altar and the ritual consisted of converting the circle into a square of an identical area. There we see the beginnings of geometry!

In his famous paper on the origin of mathematics, Seidenberg (1978) concluded: "Old-Babylonia [1700 BC] got the theorem of Pythagoras from India or that both Old-Babylonia and India got it from a third source. Now the Sanskrit scholars do not give me a date so far back as 1700 B.C. Therefore I *postulate* a pre-Old-Babylonian (i.e., pre-1700 B.C.) source of the kind of geometric rituals we see preserved in the Sulvasutras, or at least for the *mathematics* involved in these rituals." That was before archaeological finds disproved the earlier assumption of a break in Indian civilization in the second millennium B.C.E.; it was this assumption of the Sanskritists that led Seidenberg to postulate a third earlier source. Now with our new knowledge, Seidenberg's conclusion of India being the source of the geometric and mathematical knowledge of the ancient world fits in with the new chronology of the texts.

Astronomy

Using hitherto neglected texts related to ritual and the Vedic indices, an astronomy of the third millennium B.C.E. has been discovered (Kak 1994a; 1995a,b). Here the altars symbolized different parts of the year. In one ritual, pebbles were placed around the altars for the earth, the atmosphere, and the sky. The number of these pebbles were 21, 78, and 261, respectively. These numbers add up to the 360 days of the year. There were other features related to the design of the altars which suggested that the ritualists were aware that the length of the year was between 365 and 366 days.

The organization of the Vedic books was also according to an astronomical code. To give just one simple example, the total number of verses in all the Vedas is 20,358 which

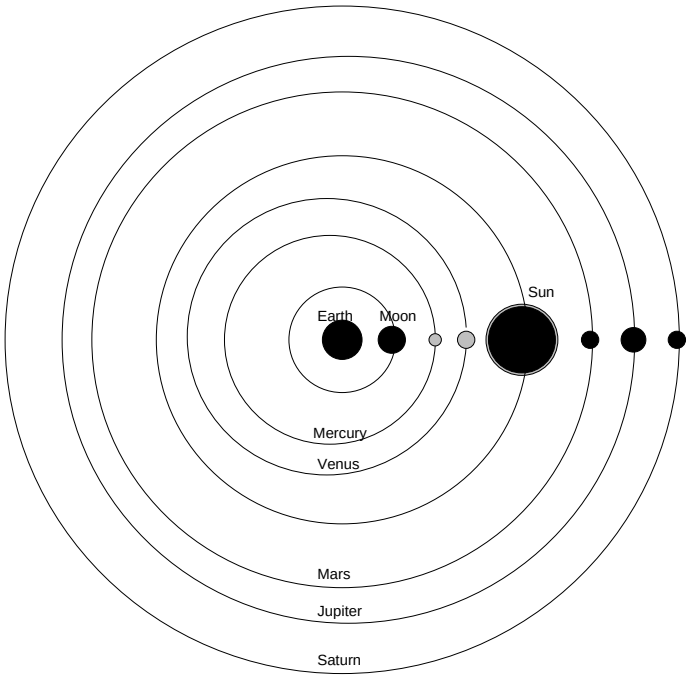

Figure 2: The Vedic planetary model

equals 261×78, a product of the sky and atmosphere numbers! The Vedic ritual followed the seasons hence the importance of astronomy.

The second millennium text Vedanga Jyotisha went beyond the earlier calendrical astronomy to develop a theory for the mean motions of the sun and the moon. This marked the beginnings of the application of mathematics to the motions of the heavenly bodies.

Planetary knowledge

The Vedic planetary model is given in Figure 2. The sun was taken to be midway in the skies. A considerable amount of Vedic mythology regarding the struggle between the demons and the gods is a metaphorical retelling of the motions of Venus and Mars (Frawley 1994).

The famous myth of Vishnu's three strides measuring the universe becomes intelligible when we note that early texts equate Vishnu and Mercury. The myth appears to celebrate the first measurement of the period of Mercury (Kak 1996a) since three periods equals the number assigned in altar ritual to the heavens. Other arguments suggest that the Vedic people knew the periods of the five classical planets.

Writing

Cryptological analysis has revealed that the Brahmi script of the Mauryan times evolved out of the third millennium Sarasvati (Indus) script. The Sarasvati script was perhaps the first true alphabetic script. The worship of Sarasvati as the goddess of learning remembers the development of writing on the banks of the Sarasvati river. It also appears that the symbol

for zero was derived from the fish sign that stood for "ten" in Brahmi and this occurred around 50 B.C.E.-50 C.E. (Kak 1994b).

Binary numbers

Barend van Nooten (1993) has shown that binary numbers were known at the time of Pingala's *Chhandahshastra*. Pingala, who lived around the early first century B.C.E., used binary numbers to classify Vedic meters. The knowledge of binary numbers indicates a deep understanding of arithmetic. A binary representation requires the use of only two symbols, rather than the ten required in the usual decimal representation, and it has now become the basis of information storage in terms of sequences of 0s and 1s in modern-day computers.

Music

Ernest McClain (1978) has described the tonal basis of early myth. McClain argues that the connections between music and myth are even deeper than astronomy and myth. The invariances at the basis of tones could very well have served as the ideal for the development of the earliest astronomy. The tonal invariances of music may have suggested the search of similar invariances in the heavenly phenomena.

The Samaveda, where the hymns were supposed to be sung, was compared to the sky. Apparently, this comparison was to emphasize the musical basis of astronomy. The Vedic hymns are according to a variety of meters; but what purpose, if any, lay behind a specific choice is unknown.

Grammar

Panini's grammar (6th century B.C.E. or earlier) provides 4,000 rules that describe the Sanskrit of his day completely. This grammar is acknowledged to be one of the greatest intellectual achievements of all time. The great variety of language mirrors, in many ways, the complexity of nature. What is remarkable is that Panini set out to describe the entire grammar in terms of a *finite* number of rules. Frits Staal (1988) has shown that the grammar of Panini represents a universal grammatical and computing system. From this perspective it anticipates the logical framework of modern computers (Kak 1987).

Medicine

There is a close parallel between Indian and Greek medicine. For example, the idea of breath (*prana* in Sanskrit, and *pneuma* in Greek) is central to both. Jean Filliozat (1970) has argued that the idea of the correct association between the three elements of the wind, the gall, and the phlegm, which was described first by Plato in Greek medicine, appears to be derived from the earlier *tridosha* theory of Ayurveda. Filliozat suggests that the transmission occurred via the Persian empire.

These discoveries not only call for a revision of the textbook accounts of Indian science but also call for new research to assess the impact on other civilizations of these ideas.

3 Rhythms of life

We have spoken before of how the Vedas speak of the connections between the external and the internal worlds. The hymns speak often of the stars and the planets. These are sometimes the luminaries in the sky, or those in the firmament of our inner landscapes or both.

To the question on how can the motions of an object, millions of miles away, have any influence on the life of a human being one can only say that the universe is interconnected. In this ecological perspective the physical planets do not influence the individual directly. Rather, the intricate clockwork of the universe runs on forces that are reflected in the periodicities of the astral bodies as also the cycles of behaviors of all terrestrial beings and plants.

It is not the gravitational pull of the planet that causes a certain response, but an internal clock governed by the genes. We know this because in some mutant organisms the internal clock works according to periods that have no apparent astronomical basis. So these cycles can be considered to be a manifestation of the motions of the body's inner "planets." In the language of evolution theory one would argue that these periods get reflected in the genetic inheritance of the biological system as a result of the advantage over millions of years that they must have provided for survival.

The most fundamental rhythms are matched to the periods of the sun or the moon. It is reasonable to assume that with their emphasis on time bound rituals and the calendar, the ancients had discovered many of the biological periods. This would include the 24-hour-50-minute circadian rhythm, the connection of the menstrual cycle with the motions of the moon, the life cycles of various plants, and the semimonthly estrus cycle of sheep, the three-week cycles of cattle and pigs, and the six-month cycle of dogs.

The moon (Soma) is called the "lord of speech" (Vachaspati) in the Rigveda. It is also taken to awaken eager thoughts. Other many references suggest that in the Rigvedic times the moon was taken to be connected with the mind.

This is stated most directly in the the famous Purushasukta, the Cosmic Man hymn, of the Rigveda where it is stated that the mind is born of the moon and in Shatapatha Brahmana where we have: "the mind is the moon." Considering the fact that the relationships between the astronomical and the terrestrial were taken in terms of periodicities, doubtless, this slogan indicates that the mind is governed by the period of the moon.

> *Fire, having become speech, entered the mouth*
> *Air, becoming scent, entered the nostrils*
> *The sun, becoming sight, entered the eyes*
> *The regions becoming hearing, entered the ears*
> *The plants, becoming hairs, entered the skin*
> *The moon, having become mind, entered the heart.*
>
> —Aitreya Aranyaka 2.4.2.4

This verse from the Upanishadic period speaks at many levels. At the literal level there is an association of the elements with various cognitive centers. At another level, the verse connects the time evolution of the external object to the cognitive center.

Fire represents consciousness and this ebbs and flows with a daily rhythm. Air represents seasons so here the rhythm is longer. The sun and sight have a 24-hour cycle. The regions denote other motions in the skies so hearing manifests cycles that are connected to the planets. The plants have daily and annual periods; the hairs of the body have an annual period. The mind has a period of 24 hours and 50 minutes like that of the moon.

What are the seats of these cycles? According to tantra the chakras of the body are the centers of the different elements as well as cognitive capacities and rhythms related to "internal planets." The knowledge of these rhythms appears to have led to astrology.

4 Cosmology

We have seen how the logical apparatus that was brought to bear on the outer world was applied to the analysis of the mind. But the question remains: How does inanimate matter come to have awareness? This metaphysical question was answered by postulating entities for smell, taste, form, touch, and sound as in Figure 1. In the Sankhya system, a total of twenty-four such categories are assumed. These categories are supposed to emerge at the end of a long chain of evolution and they may be considered to be material. The breath of life into the instruments of sight, touch, hearing and so on is provided by the twenty-fifth category, which is *purusha*, the soul.

The recursive Vedic world-view requires that the universe itself go through cycles of creation and destruction. This view became a part of the astronomical framework and ultimately very long cycles of billions of years were assumed. The Sankhya evolution takes the life forms to evolve into an increasingly complex system until the end of the cycle.

The categories of Sankhya operate at the level of the individual as well. Life mirrors the entire creation cycle and cognition mirrors a life-history. Surprisingly similar are the modern slogan: ontogeny is phylogeny, and microgeny (the cognitive process) is a speeded-up ontogeny (Brown 1994).

5 Concluding Remarks

We are in the midst of a paradigm shift in our understanding of Vedic science and cosmology. We now know that measurement astronomy is to be dated to at least the third millennium B.C.E. which is more than a thousand years earlier than was believed only a decade ago; and mathematics and geometry date to at least the beginning of the second millennium B.C.E. Indian mythology is being interpreted in terms of its underlying astronomy or/and cognitive science. We find that many Indians dates are much earlier than the corresponding dates elsewhere. What does it all mean for our understanding of the Indian civilization and its interactions with Mesopotamia, Egypt, China and Greece? Was Indian knowledge carried to the other nations or do we have a case here for independent discovery in different places?

Contemporary science has begun to examine Vedic theories on the nature of the "self" and see if they might be of value in the search for a science of consciousness (e.g. Kak 1996b). Man has mastered the outer world and Vedic science formed the basis for that enterprise; it

is now possible that the exploration of the inner world, which is the heart of modern science, will also be along paths long heralded by Vedic rishis.

2

In the earliest period of Indian science, it is exceptional when we know the authorship of a text or an idea. For example, although Lagadha (c. 1400 B.C.E.) is the author of Vedanga Jyotisha we do not know if its astronomy was developed by him or if he merely summarized what was then well known. Likewise we are not sure of the individual contributions in the Shulba Sutras, of Baudhayana, Apastamba, and other authors, which describe geometry, or Pingala's Chhandahsutra which shows how to count in a binary manner. The major exception to the anonymous nature of early Indian science is the grammatical tradition starting with Panini. This tradition is a wonderful application of the scientific method where the infinite variety of linguistic data is generated by means of a limited number of rules.

With Aryabhata of Kusumapura (born 476), we enter a new phase in which it becomes easier to trace the authorship of specific ideas. But even here there remain other aspects which are not so well understood. For example, the evolution of Indian medicine is not as well documented as that of Indian mathematics. Neither do we understand well the manner in which the philosophical basis underlying Indian science evolved.

Thus many texts speak of the relativity of time and space—abstract concepts that developed in the scientific context just a hundred years ago. The Puranas speak of countless universes, time flowing at different rates for different observers and so on.

The Mahabharata speaks of an embryo being divided into one hundred parts each becoming, after maturation in a separate pot, a healthy baby; this is how the Kaurava brothers are born. There is also mention of an embryo, conceived in one womb, being transferred to the womb of another woman from where it is born; the transferred embryo is Balarama and this is how he is a brother to Krishna although he was born to Rohini and not to Devaki.

There is an ancient mention of space travellers wearing airtight suits in the epic Mahabharata which may be classified as an early form of science fiction. According to the well-known Sanskritist J.A.B. van Buitenen, in the accounts in Book 3 called "The Razing of Saubha" and "The War of the Yakshas":

> the aerial city is nothing but an armed camp with flame-throwers and thundering cannon, no doubt a spaceship. The name of the demons is also revealing: they were Nivātakavacas, "clad in airtight armor," which can hardly be anything but space suits. (van Buitenen, 1975, page 202)

Universes defined recursively are described in the famous episode of Indra and the ants in Brahmavaivarta Purana. Here Vishnu, in the guise of a boy, explains to Indra that the ants he sees walking on the ground have all been Indras in their own solar systems in different times! These flights of imagination are to be traced to more than a straightforward generalization of the motions of the planets into a cyclic universe. They must be viewed in

the background of an amazingly sophisticated tradition of cognitive and analytical thought (see e.g. Staal 1988; Kak 1994).

The context of modern science fiction books is clear: it is the liberation of the earlier modes of thought by the revolutionary developments of the 20th century science and technology. But how was science fiction integrated into the mainstream of Indian literary tradition two thousand years ago? What was the intellectual ferment in which such sophisticated ideas arose?

I do not answer these questions directly. My goal is to provide a survey so that the reader can form his or her own conclusions. I begin with an account of Indian mathematics and astronomy from the time of Aryabhata until the period of the Kerala school of astronomy. Then I consider material from one randomly chosen early text, Yoga-Vasishtha, to convey basic Indian notions about time, space, and matter. Yoga-Vasishtha has been dated variously as early as the sixth century and as late as the 14th century. It claims to be book regarding consciousness but it has many fascinating passages on time, space, matter and the nature of experience. We present a random selection that has parallels with some recent speculations in physics. Lastly, I take up the question of the conceptions behind the Shri Yantra, whose origins, some scholars believe, go back to the age of Atharvaveda.

6 Mathematics and astronomy

One would expect that the development of early Indian mathematics and astronomy went through several phases but we don't have sufficient data to reconstruct these phases. A certain astronomy has been inferred from the Vedic books, but there existed additional sources which have not survived. For example, there were early astronomical siddhantas of which we know now only from late commentaries written during the Gupta period (320-600); this period provided a long period of stability and prosperity that saw a great flowering of art, literature, and the sciences.

Of the eighteen early siddhantas the summaries of only five are available now. Perhaps one reason that the earlier texts were lost is because their theories were superseded by the more accurate later works. In addition to these siddhantas, practical manuals, astronomical tables, description of instruments, and other miscellaneous writings have also come down to us (Sarma 1985). The Puranas also have some material on astronomy.

Aryabhata

Aryabhata is the author of the first of the later siddhantas called Aryabhatiyam which sketches his mathematical, planetary, and cosmic theories. This book is divided into four chapters: (i) the astronomical constants and the sine table, (ii) mathematics required for computations, (iii) division of time and rules for computing the longitudes of planets using eccentrics and epicycles, (iv) the armillary sphere, rules relating to problems of trigonometry and the computation of eclipses.

The parameters of Aryabhatiyam have, as their origin, the commencement of Kaliyuga on Friday, 18th February, 3102 B.C.E. He wrote another book where the epoch is a bit different.

Aryabhata took the earth to spin on its axis; this idea appears to have been his innovation. He also considered the heavenly motions to go through a cycle of 4.32 billion years; here he went with an older tradition, but he introduced a new scheme of subdivisions within this great cycle. According to the historian Hugh Thurston, "Not only did Aryabhata believe that the earth rotates, but there are glimmerings in his system (and other similar systems) of a possible underlying theory in which the earth (and the planets) orbits the sun, rather than the sun orbiting the earth. The evidence is that the basic planetary periods are relative to the sun."

That Aryabhata was aware of the relativity of motion is clear from this passage in his book,"Just as a man in a boat sees the trees on the bank move in the opposite direction, so an observer on the equator sees the stationary stars as moving precisely toward the west."

Varahamihira

Varahamihira (died 587) lived in Ujjain and he wrote three important books: Panchasiddhantika, Brihat Samhita, and Brihat Jataka. The first is a summary of five early astronomical systems including the Surya Siddhanta. (Incidently, the modern Surya Siddhanta is different in many details from this ancient one.) Another system described by him, the Paitamaha Siddhanta, appears to have many similarities with the ancient Vedanga Jyotisha of Lagadha.

Brihat Samhita is a compilataion of an assortment of topics that provides interesting details of the beliefs of those times. Brihat Jataka is a book on astrology which appears to be considerably influenced by Greek astrology.

Brahmagupta

Brahmagupta of Bhilamala in Rajasthan, who was born in 598, wrote his masterpiece, Brahmasphuta Siddhanta, in 628. His school, which was a rival to that of Aryabhata, has been very influential in western and northern India. Brahmagupta's work was translated into Arabic in 771 or 773 at Baghdad and it became famous in the Arabic world as Sindhind.

One of Brahmagupta's chief contributions is the solution of a certain second order indeterminate equation which is of great significance in number theory.

Another of his books, the Khandakhadyaka, remained a popular handbook for astronomical computations for centuries.

Bhaskara

Bhaskara (born 1114), who was from the Karnataka region, was an outstanding mathematician and astronomer. Amongst his mathematical contributions is the concept of differentials. He was the author of Siddhanta Shiromani, a book in four parts: (i) Lilavati on arithmetic, (ii) Bijaganita on algebra, (iii) Ganitadhyaya, (iv) Goladhyaya on astronomy. He epicyclic-eccentric theories of planetary motions are more developed than in the earlier siddhantas.

Subsequent to Bhaskara we see a flourishing tradition of mathematics and astronomy in Kerala which saw itself as a successor to the school of Aryabhata. We know of the

contributions of very many scholars in this tradition, of whom we will speak only of two below.

Madhava

Madhava (c. 1340-1425) developed a procedure to determine the positions of the moon every 36 minutes. He also provided methods to estimate the motions of the planets. He gave power series expansions for trigonometric functions, and for pi correct to eleven decimal places.

Nilakantha Somayaji

Nilakantha (c. 1444-1545) was a very prolific scholar who wrote several works on astronomy. It appears that Nilakantha found the correct formulation for the equation of the center of the planets and his model must be considered a true heliocentric model of the solar system. He also improved upon the power series techniques of Madhava.

The methods developed by the Kerala mathematicians were far ahead of the European mathematics of the day.

7 Concepts of space, time, and matter

Yoga-Vasishtha (YV) is an ancient Indian text, over 29,000 verses long, traditionally attributed to Valmiki, author of the epic Ramayana which is over two thousand years old. But the internal evidence of the text indicates that it was authored or compiled later. It has been dated variously as early as the sixth century AD or as late as the 13th or the 14th century (Chapple 1984). Dasgupta (1975) dated it about the sixth century AD on the basis that one of its verses appears to be copied from one of Kalidasa's plays considering Kalidasa to have lived around the fifth century. The traditional date of of Kalidasa is 50 BC and new arguments (Kak 1990) support this earlier date so that the estimates regarding the age of YV are further muddled.

YV may be viewed as a book of philosophy or as a philosophical novel. It describes the instruction given by Vasishtha to Rama, the hero of the epic Ramayana. Its premise may be termed radical idealism and it is couched in a fashion that has many parallels with the notion of a participatory universe argued by modern philosophers. Its most interesting passages from the scientific point of view relate to the description of the nature of space, time, matter, and consciousness. It should be emphasized that the YV ideas do not stand in isolation. Similar ideas are to be found in the Vedic texts. At its deepest level the Vedic conception is to view reality in a monist manner; at the next level one may speak of the dichotomy of mind and matter. Ideas similar to those found in YV are also encountered in Puranas and Tantric literature.

We provide a random selection of these passages taken from the abridged translation of the book done by Venkatesananda (1984).

Time

- Time cannot be analyzed... Time uses two balls known as the sun and the moon for its pastime. [16]
- The world is like a potter's wheel: the wheel looks as if it stands still, though it revolves at a terrific speed. [18]
- Just as space does not have a fixed span, time does not have a fixed span either. Just as the world and its creation are mere appearances, a moment and an epoch are also imaginary. [55]
- Infinite consciousness held in itself the notion of a unit of time equal to one-millionth of the twinkling of an eye: and from this evolved the time-scale right upto an epoch consisting of several revolutions of the four ages, which is the life-span of one cosmic creation. Infinite consciousness itself is uninvolved in these, for it is devoid of rising and setting (which are essential to all time-scales), and it devoid of a beginning, middle and end. [72]

Space

- There are three types of space—the psychological space, the physical space and the infinite space of consciousness. [52]

  The infinite space of individed consciousness is that which exists in all, inside and outside... The finite space of divided consciousness is that which created divisions of time, which pervades all beings... The physical space is that in which the elements exist. The latter two are not independent of the first. [96]
- *Other universes.* On the slopes of a far-distant mountain range there is a solid rock within which I dwell. The world within this rock is just like yours: it has its own inhabitants, ...the sun and the moon and all the rest of it. I have been in it for countless aeons. [402]
- The entire universe is contained in a subatomic partice, and the three worlds exist within one strand of hair. [404]

Matter

- In every atom there are worlds within worlds. [55]
- (There are) countless universes, diverse in composition and space-time structure... In every one of them there are continents and mountains, villages and cities inhabited by people who have their time-space and life-span. [401-2]

Experience

- Direct experience alone is the basis for all proofs... That substratum is the experiencing intelligence which itself becomes the experiencer, the act of experiencing, and the experience. [36]

- Everyone has two bodies, the one physical and the other mental. The physical body is insentient and seeks its own destruction; the mind is finite but orderly. [124]

- I have carefully investigated, I have observed everything from the tips of my toes to the top of my head, and I have not found anything of which I could say, 'This I am.' Who is 'I'? I am the all-pervading consciousness which is itself not an object of knowledge or knowing and is free from self-hood. I am that which is indivisible, which has no name, which does not undergo change, which is beyond all concepts of unity and diversity, which is beyond measure. [214]

- I remember that once upon a time there was nothing on this earth, neither trees and plants, nor even mountains. For a period of eleven thousand years the earth was covered by lava. In those days there was neither day nor night below the polar region: for in the rest of the earth neither the sun nor the moon shone. Only one half of the polar region was illumined.

  Then demons ruled the earth. They were deluded, powerful and prosperous, and the earth was their playground.

  Apart from the polar region the rest of the earth was covered with water. And then for a very long time the whole earth was covered with forests, except the polar region. Then there arose great mountains, but without any human inhabitants. For a period of ten thousand years the earth was covered with the corpses of the demons. [280]

Mind

- The same infinite self conceives within itself the duality of oneself and the other. [39]

- Thought is mind, there is no distinction between the two. [41]

- The body can neither enjoy nor suffer. It is the mind alone that experiences. [109-110]

- The mind has no body, no support and no form; yet by this mind is everything consumed in this world. This is indeed a great mystery. He who says that he is destroyed by the mind which has no substantiality at all, says in effect that his head was smashed by the lotus petal... The hero who is able to destroy a real enemy standing in front of him is himself destroyed by this mind which is [non-material].

- The intelligence which is other than self-knowledge is what constitutes the mind. [175]

Complementarity

- The absolute alone exists now and for ever. When one thinks of it as a void, it is because of the feeling one has that it is not void; when one thinks of it as not-void, it is because there is a feeling that it is void. [46]
- All fundamental elements continued to act on one another—as experiencer and experience—and the entire creation came into being like ripples on the surface of the ocean. And, they are interwoven and mixed up so effectively that they cannot be extricated from one another till the cosmic dissolution. [48]

Consciousness

- The entire universe is forever the same as the consciousness that dwells in every atom. [41]
- The five elements are the seed fo which the world is the tree; and the eternal consciousness if the seed of the elements. [48]
- Cosmic consciousness alone exists now and ever; in it are no worlds, no created beings. That consciousness reflected in itself appears to be creation. [49]
- This consciousness is not knowable: when it wishes to become the knowable, it is known as the universe. Mind, intellect, egotism, the five great elements, and the world—all these innumerable names and forms are all consciousness alone. [50]
- The world exists because consciousness is, and the world is the body of consciousness. There is no division, no difference, no distinction. *Hence the universe can be said to be both real and unreal: real because of the reality of consciousness which is its own reality, and unreal because the universe does not exist as universe, independent of consciousness.* [50]
- Consciousness is pure, eternal and infinite: it does not arise nor cease to be. It is ever there in the moving and unmoving creatures, in the sky, on the mountain and in fire and air. [67]
- Millions of universes appear in the infinite consciousness like specks of dust in a beam of light. In one small atom all the three worlds appear to be, with all their components like space, time, action, substance, day and night. [120]
- The universe exists in infinte consciousness. Infinite consciousness is unmanifest, though omnipresent, even as space, though existing everywhere, is manifest. [141]
- The manifestation of the omnipotence of infinite consciousness enters into an alliance with time, space and causation. Thence arise infinite names and forms. [145]
- The Lord who is infinite consciousness is the silent but alert witness of this cosmic dance. He is not different from the dancer (the cosmic natural order) and the dance (the happenings). [296]

The YV model of knowledge

YV is not written as a systematic text. But the above descriptions may be used to reconstruct its system of knowledge.

YV appears to accept the idea that laws are intrinsic to the universe. In other words, the laws of nature in an unfolding universe will also evolve. According to YV, new information does not emerge out the inanimate world but it is a result of the exchange between mind and matter.

It also appears to accept consciousness as a kind of fundamental field that pervades the whole universe.

One might speculate that the parallels between YV and some recent ideas of physics are a result of the inherent structure of the mind.

8 The Shri Yantra

Although our immediate information on the Shri Yantra (SY) comes from medieval sources, some scholars have seen the antecedents of the yantra in Book 10 of the Atharvaveda. The Shri Yantra consists of nine triangles inscribed within a circle which leads to the formation of 43 little triangles (Figure 1) (Kulaichev 1984). Whatever the antiquity of the idea of this design, it is certain that the yantra was made both on flat and curved surfaces during the middle ages. The drawing of the triangles on the curved surface implies the knowledge that sum of the angles of such triangles exceeds 180 degrees.

The question that the physicist and historian of science John Barrow (1992) has asked is whether these shapes intimate a knowledge of non-Euclidean geometry in India centuries before its systematic study in Europe.

It is possible that the yantras were made by craftsmen who had no appreciation of its mathematical properties. But scholars have argued that the intricacies of the construction of this yantra requires mathematica knowledge.

9 Concluding Remarks

This has been a survey of some topics that have interested me in the past decade. If the revisions in our understanding required for these topics are indicative of other subjects also then we are in for a most radical rewriting of the history of science in India.

Our survey of these topics did not stress enough one aspect of Indian thought that sets it apart from that of most other nations, viz. the belief that thought by itself can lead to objective knowledge. Being counter to the reductionist program of mainstream science, this aspect of Indian thought has been bitterly condemned by most historians of science as being irrational and mystical. Now that reductionism is in retreat in mainstream science itself one would expect a less emotional assessment of Indian ideas. We can hope to address issues such as how do some ideas in India happen to be ages ahead of their times.

Students of scientific creativity increasingly accept that conceptual advances do not appear in any rational manner. Might then one accept the claim of Srinivasa Ramanujan that

his theorems were revealed to him in his dreams by the goddess Namagiri? This claim, so persistently made by Ramanujan, has generally been dismissed by his biographers (see, for example, Kanigel, 1991). Were Ramanujan's astonishing discoveries instrumented by the autonomously creative potential of consciousness, represented by him by the image of Namagiri? If that be the case then the marvellous imagination shown in Yoga-Vasishtha and other Indian texts becomes easier to comprehend.

References

Sarma, K.V. 1985. A survey of source materials. *Indian Journal of History of Science* 20.1-20.

Staal, F. 1988. *Universals.* Chicago: University of Chicago Press.

Venkatesananda, S. (tr.), 1984. *The Concise Yoga Vāsiṣṭha.* Albany: State University of New York Press.

Barrow, J. 1992. *Pi in the Sky.* Oxford: Oxford University Press.

Brown, J.W. 1994. Morphogenesis and mental process. *Development and Psychopathology.* 6.551-563.

van Buitenen, J.A.B. 1975. *The Mahābhārata*, vol. 2. Chicago: University of Chicago Press.

Chapple, C. 1984. Introduction and bibliography in Venkatesananda (1984).

Dasgupta, S. 1975 (1932). *A History of Indian Philosophy.* Delhi: Motilal Banarsidass.

Feuerstein, G., S. Kak and D. Frawley, 1995. *In Search of the Cradle of Civilization.* Wheaton: Quest Books.

Filliozat, J. 1970. The expansion of Indian medicine abroad. In Lokesh Chandra (ed.) *India's Contributions to World Thought and Culture.* Madras: Vivekananda Memorial Committee. 67-70.

Francfort, H.-P. 1992. Evidence for Harappan irrigation system in Haryana and Rajasthan. *Eastern Anthropologist.* 45.87-103.

Frawley, D. 1994. Planets in the Vedic literature. *Indian Journal of History of Science.* 29.495-506.

Kak, S. 1986. *The Nature of Physical Reality.* New York: Peter Lang.

_____ 1987. The Paninian approach to natural language processing. *Intl. Journal of Approximate Reasoning.* 1.117-130.

_____ 1990. Kalidasa and the Agnimitra problem. *Journal of the Oriental Institute* 40.51-54.

_____ 1994a. *The Astronomical Code of the Ṛgveda.* New Delhi: Aditya.

_____ 1994b. The evolution of writing in India. *Indian Journal of History of Science.* 28.375-388.

_____ 1994c. *India at Century's End.* New Delhi: VOI.

_____ 1995a. The astronomy of the age of geometric altars. *Quarterly Journal of the Royal Astronomical Society.* 36.385-396.

_____ 1995b. From Vedic science to Vedānta. *The Adyar Library Bulletin.* 59.1-36.

_____ 1996a. Knowledge of planets in the third millennium B.C. *Quarterly Journal of the Royal Astronomical Society.* 37.709-715.

_____ 1996b. Reflections in clouded mirrors: selfhood in animals and machines. In Pribram, K.H. and J. King (eds.) *Learning as Self-Organization.* Mahwah, NJ: Lawrence Erlbaum.

Kanigel, R. 1991. *The Man Who Knew Infinity: A Life of the Mathematical Genius, Ramanujan.* New York: C. Scribner's.

Kulaichev, A.P. 1984. Ṥriyantra and its mathematical properties. *Indian Journal of History of Science* 19.279-292.

McClain, E.G. 1978. *The Myth of Invariance.* Boulder: Shambhala.

Sarma, K.V. 1985. A survey of source materials. *Indian Journal of History of Science* 20.1-20.

Seidenberg, A. 1978. The origin of mathematics. *Archive for History of Exact Sciences.* 18.301-342.

Sengupta, P.C. 1947. *Ancient Indian Chronology.* Calcutta: University of Calcutta Press.

Staal, F. 1988. *Universals.* Chicago: University of Chicago Press.

van Nooten, B. 1993. Binary numbers in Indian antiquity. *Journal of Indian Philosophy.* 21.31-50.

Venkatesananda, S. (tr.), 1984. *The Concise Yoga Vāsiṣṭha.* Albany: State University of New York Press.