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Cultural Specificities in the History of Indian Science

by

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Cultural Specificities in the History of Indian Science*

It is a great honour for me to have been invited to deliver the first Professor G.C. Pande Memorial Lecture. It was my privilege to meet him on a few occasions, and I am familiar with some of his writings on Indian culture. Professor G.C. Pande struck me as a man obsessed with knowledge, and I thought the topic of this lecture would have been in tune with his interests. Indeed, India, a knowledge-centred civilization with intellectual traditions nurtured for at least three millennia, has contributed her fair share of innovations to the fields of astronomy, mathematics, medicine and a host of technologies from metallurgy to textile to transport.[1] Western historians of science have acknowledged some of those contributions and are gradually becoming aware of others.[2] Hopefully a genuine awareness of the field will grow in India too, where it has been studiously ignored in mainstream academia. What is often overlooked, however, is the cultural framework within which those advances took place, a framework that discernibly oriented some of the advances of Indian science.

India, a knowledge-centred civilization with intellectual traditions nurtured for at least three millennia, has contributed her fair share of innovations to the fields of astronomy, mathematics, medicine and a host of technologies.

But let us first pause and reflect on the usual definition of 'science' as 'the pursuit of the fundamental laws of the universe'. It is, of course, a

* Michel Danino delivered the lecture on *Cultural Specificities in the History of Indian Science* on September 12, 2011 at the IIC as the inaugural lecture for *Vak*, a lecture series initiated in memory of the renowned Indologist, Dr. Govind Chandra Pande (July 1923-May 2011).

recent one: in ancient times, this pursuit made use of mythology, cosmogony, rituals, spirituality, poetry, philosophy, art, etc.—all of which are legitimate human expressions of abstract or symbolic thought. 'Pure science' as we understand it did not exist; it lay scattered across all those approaches. And in fact, the advent of the modern scientific method in the nineteenth century has not invalidated any of them: a poet's description of a sunrise, a priest's incantations to the dawn, a painter's play with its changing hues or a philosopher's reflection on light and darkness are as valid as a physicist's observation of the phenomena of diffraction at sunrise. They all hold a truth within the limits of their own realm; none has an exclusive claim to completeness; none is 'truer' than the other. In a way, the ancient attitude was probably closer to the truth, because it was not so fragmenting: it tried to grasp the whole, while science today is generally content studying one small compartment of knowledge after another, rarely taking time to build an overall picture, and perhaps ill-equipped to do so.

India's Organization of Knowledge

If pure science did not exist, and if, therefore, 'mathematics', 'astronomy' or 'chemistry' only recently began to be defined as separate disciplines, how did the ancients fit scientific knowledge in their scheme of things? Let us first remember that the four Vedas (*Rig, Yajur, Sāma, Atharva*) were followed by the commentaries called *Brāhmanas*, the philosophical texts known as *Upanishads* and the literature that goes by the name of *Vedāngas*, or 'limbs of the *Vedas*'.

The *Vedāngas* (Fig. 1) are so called because their knowledge was deemed essential to a proper understanding, practice and transmission of the *Vedas*. Hence their focus on phonetics, metrics, grammar, etymology and ritual, the last of which involved the construction of complex fire altars that obeyed certain geometric rules: India's first geometry was thus of a ritual nature (we will return to the literature produced, the *Shulba Sutras*). The last *Vedānga, jyotisha*, was a combination of astronomy and mathematics (but not astrology, which did not exist as a separate discipline until later). *Jyotisha* was required to keep track of celestial bodies around the days, lunar months, seasons, and luni-solar years; rhythm was essential to the observance of sacrifices and festivals, and nothing less than the universe was employed to beat time.

Between these two *Vedangas*, then, we shall find our 'science'. Let us now see how it took shapes specific to India.

The Infinite in Mathematics

Right from India's first extant text—the *Rig-Veda*—we note an interesting tendency to reach for higher and higher numbers. A typical hymn goes thus:

Indra, come hitherward with **two** Bay Coursers, come thou with **four**, with **six** when invocated.

> Come thou with **eight**, with **ten**, to drink the Soma. Here is the juice, brave Warrior: do not scorn it.
>
> O Indra, come thou hither having harnessed thy car with **twenty**, thirty, **forty** horses.
>
> Come thou with **fifty** well-trained coursers, Indra, **sixty** or **seventy**, to drink the Soma.
>
> Come to us hitherward, O Indra, carried by **eighty**, **ninety**, or a **hundred** horses. ...[3]

A few centuries later, we find the following numbers in the *Yajur Veda: eka* (1), *dasha* (10), *shata* (10^2), *sahasra* (10^3), *ayuta* (10^4), *niyuta* (10^5), *prayuta* (10^6), *arbuda* (10^7), *nyarbuda* (10^8), *samudra* (10^9), *madhya* (10^{10}), *anta* (10^{11}), and finally *parardha* (10^{12}), that is, a billion.

Why take the trouble of building up such a metaphorical list? It is metaphorical, since these numbers can have no physical reality. Of course they represent an *increase*, and increase is a constant in the *Rig-Veda*, but why such a regular one that faithfully follows multiples of ten? Apart from the important fact that this points to an early notion of a decimal system, it is clear that the composer would have no reason to stop at a hundred, and following that system, could have gone on and on. Indeed, the *Rig-Vedic* hymns go on to a thousand, ten thousand, and finally a hundred thousand (a lakh).[4]

A few centuries later, we find the following numbers in the *Yajur Veda: eka* (1), *dasha* (10), *shata* (10^2), *sahasra* (10^3), ayuta (10^4), *niyuta* (10^5), *prayuta* (10^6), *arbuda* (10^7), *nyarbuda* (10^8), *samudra* (10^9), *madhya* (10^{10}), *anta* (10^{11}), and finally *parārdha* (10^{12}), that is, a billion. Again, there are 'metaphorical' numbers, and with clearly no application whatever in a Vedic society. But why stop there? Take the *Ramayana*: at one point, Valmiki describes the strength of Rama's army to be precisely 1000 *koti* + 100 *shanku* + 1000 *mahāshanku* + 100 *vrinda* +1000 *mahāvrinda* + 100 *padma* + 1000 *mahāpadma* + 100 *kharva* + 100 *samudra* + 100 *mahaugha* + 1 *koti mahaugha* + 1 *Vibhīshana* and his four ministers, which is equal to $5 + 10^{10} + 10^{14} + 10^{20} + 10^{24} + 10^{30} + 10^{34} + 10^{40} + 10^{44} + 10^{52} + 10^{57} + 10^{62}$. I shall not attempt to work out the sum, but it is a trifle over the last term, which is a billion billion billion billion billions. Again, why stop there at all? Numbers grew by leaps and bounds in Jaina literature, ultimately exceeding 10^{250}. The *Anuyogadvara-sutra* states the sum of human beings of the creation to be 2^{96} (we should be thankful that facts are otherwise). Such large numbers were used to represent long periods in a colossal time-scale; for according to the Jaina doctrine, the universe is indestructible because it is infinite in both time and space.

In the Buddhist work *Lalitavistara*, the Bodhisattva enumerated to a mathematician numerals in multiples of 100, starting from a *koti* (our crore or 10^7) and going up to a *tallakshana* (10^{53}). Number 10^{140} (which is, of course, 1 followed by 140 zeros) was named *asamkheya*—innumerable or uncountable—a word that the *Lalitavistara* poetically defines as the number of raindrops falling on all the worlds for ten thousand years. The same text eventually reaches a number equivalent to 10^{421}!

Across the literature, multiples of ten up to 10^{145} had individual names (Fig. 2), as though they were friends or pets. In contrast, the Greeks had named numbers only up to 10,000 = the 'myriad'; Arabic names did not go beyond 1,000; and only in the thirteenth century did the French introduce the 'million' (the billion, trillion and quadrillion were conceived of in the seventeenth century).[5] (The Chinese, however, had in the first few centuries CE names for numbers up to 10^{80}.)[6]

Such colossal numbers and attached names could have been of no practical use; they flowed from a contemplation of this infinite universe and a desire to reach out to that infinity.

India's fascination with huge numbers is well illustrated by the Arabic legend of *chaturanga*, an early version of chess.

India's fascination with huge numbers is well illustrated by the Arabic legend of *chaturanga*, an early version of chess.[7] Sessa, a clever Brāhmana, once demonstrated this new game to a king, who was so pleased that he told him to ask for any reward. Sessa humbly requested 1 grain of wheat on the first square of the board, 2 on the second, 4 on the third, 8 on the fourth, and so on, doubling the number of grains on every square right up to the sixty-fourth. The king thought the request was ridiculously modest and insisted on a more substantial one, but Sessa declined. The royal mathematicians set about calculating the amount, but after great labour could not proceed beyond a few squares. Embarrassed, the king had mathematicians called from a neighbouring kingdom, who were familiar with the decimal place-value system and were at home with large numbers. They soon worked out the desired number of grains: $2^{64} - 1$, a colossal number that requires 20 digits to be written out in the conventional way. The savants explained to the king that even if the whole earth were sown with wheat, it would take some 73 harvests to reach such a quantity! To save the royal face, a wily minister suggested that he should open his granary to the Brāhmana and ask him to start counting the grains himself, never stopping till he reached the desired number. Sessa got the message and was never heard of again.

0	zero :	*shunya, bindu, kha, pūrna, vyoman...*
1	one :	*eka, ādi, pitāmaha, tanu, kshiti, indu...*
2	two :	*dvi, ashvin, netra, paksha...*
3	three :	*tri, guna, loka, kāla, agni...*
4	four :	*chatur, dish, yuga, iryā...*
5	five :	*pañcha, ishu, indriya, bhūta...*
6	six :	*shat, rasa, anga, shanmukha...*
7	seven :	*sapta, ashva, naga, rishi, sāgara, dvīpa...*
8	eight :	*ashta, gaja, nāga, mūrti...*
9	nine :	*nava, anka, graha, chhidra...*
10	ten :	*dasha, anguli, āshā, avatāra, dish...*
100	10^{2} :	*shata*
1000	10^{3} :	*sahasra*
10000	10^{4} :	*ayuta, dashasahasra*
100000	10^{5} :	*lakh, laksha, niyuta*
1000000	10^{6} :	*dashalaksha, prayuta*
10000000	10^{7} :	*koti, arbuda*
100000000	10^{8} :	*arbuda, vyarbuda, nyarbuda, dashakoti*
1000000000	10^{9} :	*padma, samudra, abja, ayuta, nahut*
10000000000	10^{10} :	*kharva, madhya, arbuda, samudra*
100000000000	10^{11} :	*nikharva, anta, madhya, ninnahut, salila*
1000000000000	10^{12} :	*mahāpadma, parārdha, mahābjan antya*
10000000000000	10^{13} :	*shanka, ananta, khamba, kankara*
100000000000000	10^{14} :	*samudra, pakoti, jaladhi, padma, vādava*
1000000000000000	10^{15} :	*madhya, akshiti, antya, mahāpadma*
10000000000000000	10^{16} :	*antya, madhya, kshoni*
100000000000000000	10^{17} :	*parārdha, abab, kshobhya, vrindhā*
1000000000000000000	10^{18} :	*shanka*
10000000000000000000	10^{19} :	*attata, vivahah*
100000000000000000000	10^{20} :	*kshiti*
1000000000000000000000	10^{21} :	*kotippakoti, kumud, utsanga*
10000000000000000000000	10^{22} :	*kshoba*
100000000000000000000000	10^{23} :	*bahula, gundhika*
10000000000000000000000000	10^{25} :	*nāgabala, utpala*
00000000000000000000000000	10^{27} :	*pundarika, titilambha*
00000000000000000000000000	10^{28} :	*nahuta*
00000000000000000000000000	10^{29} :	*vyavasthānaprajñapati*
00000000000000000000000000	10^{31} :	*hetuhila*
00000000000000000000000000	10^{33} :	*karahu*
00000000000000000000000000	10^{34} :	*mahāpadma*
00000000000000000000000000	10^{35} :	*hetvrindiya*
00000000000000000000000000	10^{37} :	*samāptalambha*
00000000000000000000000000	10^{39} :	*gananāgati, kharva*
00000000000000000000000000	10^{41} :	*niravadya*
00000000000000000000000000	10^{42} :	*akkhobhini*
00000000000000000000000000	10^{43} :	*mudrābala*
000000000000000000000000000	10^{45} :	*sarvabala*

and so on up to . . . 10^{145} !

In 1957, the American physicist David Bohm, who was obsessed with unveiling the deeper reality of matter, had a 'vision' almost identical to that of the *Avatamsaka Sutra*. … The universe was composed of this infinity of reflections, and of reflections of reflections. Every atom was reflecting in this way, and the infinity of these reflections was reflected in each thing; each was an infinite reflection of the whole.

Mathematics was not just about numbers of raindrops over worlds and millennia. The *Avatamsaka Sutra* (the 'Flower Garland Sutra'), a Buddhist text, depicts a network of pearls placed in heavens by Indra so that 'in each pearl one can see the reflections of all the others, as well as the reflections within the reflections and so on'. Mere poetic fancy? To most scholars, yes. But three US mathematicians took up the challenge in earnest and found that Indra's pearls would have precisely followed the arrangement of circles in a mathematical entity called a Schottky group. They worked out several actual designs of pearls fulfilling the text's apparently impossible conditions.[8] So what did its composers have in mind, since they could not have known this mathematical entity? Perhaps, simply, the direct vision of a certain truth that can take on both poetical and mathematical expressions.

Someone else saw that truth. In 1957, the American physicist David Bohm, who was obsessed with unveiling the deeper reality of matter, had a 'vision' almost identical to that of the *Avatamsaka Sutra*. 'The vision came to him,' writes his biographer F. David Peat, 'in the form of a large number of highly silvered spherical mirrors that reflected each other. The universe was composed of this infinity of reflections, and of reflections of reflections. Every atom was reflecting in this way, and the infinity of these reflections was reflected in each thing; each was an infinite reflection of the whole.'[9] An eloquent reminder that a mystical perception of reality is not India's monopoly: it is a capacity inherent in human consciousness.

Ultimately, mathematical infinity got a name of its own: *khachheda or khahara*. *Khachheda* means 'divided by *kha*', *kha* meaning 'space' or 'void', one of the names for 'zero'. 'Division by zero' gives an intuitive definition of infinity: any fraction increases in value as its denominator is reduced; as the latter tends towards zero, the fraction tends towards infinity. The term *khachheda* was introduced by the great mathematician Brahmagupta in his *Brāhmasphuta Siddhānta* (628 CE); *khahara*, with a similar meaning, was used later by another celebrated scientist, Bhāskara II or Bhāskarāchārya (twelfth century).

This was the first attempt in the world to propose a mathematical definition for infinity.

It was in the logic of things, then, that Indian savants should have been the first to conceive of infinite series and offer some important examples of them: the power expansions of trigonometric functions. Credit goes to Madhava (c. 1340–1425) of Kerala for working out the following three:

$$\mathrm{Tan}^{-1}\, x = x - \frac{x^3}{3} + \frac{x^5}{5} - + \cdots,$$

$$\mathrm{Sin}\,\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - + \cdots,$$

$$\mathrm{Cos}\,\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - + \cdots.$$

The first is known as the Gregory series, after a Scottish mathematician who worked it out in 1671—some three centuries after Madhava. As it happens, choosing x to be 1 gives us an infinite series for ϖ, which theoretically permits the calculation of any number of decimals (and Mādhava did eventually reach 11 correct decimals):

So an infatuation with infinity sometimes leads to quite pragmatic applications.

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \cdots$$

Numbers and Mythology

Not just large numbers, smaller ones too bore several names each, most of them derived from philosophical and spiritual concepts. A few examples will illustrate the point:

- *Shūnya* (or *kha*) for zero is a well-known case, but other terms for it, such as *ākāsha*, *ambara*, *vyoman* (all meaning 'sky'), *ananta* ('infinite'), *pūrna* ('full'), imply totality and wholeness rather than void, suggesting that the two concepts are simply two aspects of the same truth.
- Number **1**, *eka*, suggests the notion of indivisibility: other names for it, therefore, include *ātman*, *brahman* (the soul and Self), *sūrya* (the sun), *ādi* (the beginning),

akshara (the syllable Aum), the moon (*soma, indu*), the earth and its many names, and many more symbols of unity.

- Number **2**, *dvi*, is also named after the Ashvins, the twice-born, *Yama* (as the primordial couple of the *Rig Veda*), the two eyes, and other symbols of duality.
- Number **3**, tri, after the three Vedas, Shiva's three eyes, his trident (*trishūla*), the three worlds, the three *gunas*, the triple Agni and so on.
- Number **4**, *chatur*, after the four *āshramas* or stages of human life, the four ages (*yugas*), the four Vedas, Vishnu's arms or Brahmā's four faces.
- Number **5**, *pañca*, after the five elements, the Pāndavas or Rudra's five faces.
- Number **6**, *shat*, after the six *rāgas*, the six classical systems of philosophy (*darshanas*), Kārttikeya's six faces.
- Number **7**, *sapta*, after the seven Buddhas, the seven oceans (*sāgaras*) and islands (*dvipas*), the seven rishis, divine Mothers, rivers, days of the week, horses of Sūrya, etc.
- Number **8**, *ashta*, after the eight points of the compass or the eight mythical elephants upholding the world.
- Number **9**, *nava*, after the planets, the traditional nine jewels (*ratna*), the body's orifices, or Durgā (celebrated during the nine nights of the *Navarātri* festival).
- Number **10**, *dasha*, after Vishnu's ten avatars, the Buddha's ten powers and stages, or Ravana's ten heads.

The list goes on with 12 *adityas*, 25 *tattvas*, 27 *nakshatras*, 33 *Devas*, 49 *Vayus* ... and for larger numbers such terms would be attached together, leading to long words devoid of any meaning except mathematical.

This device fell into disuse with the spread of the decimal numeral system, but the association of spiritual and philosophical concepts with number names is yet another illustration of the absence of rigid boundaries between science and spirituality in the minds of Indian mathematicians.

The Infinite in Astronomy

To the early Indian astronomer (and most early mathematicians were first and foremost astronomers), the universe was the most immediate illustration or manifestation of the infinite.

We are familiar with the classical time scales of *Yugas*, *Mahāyugas*, *Manvantaras* (each equal to 71 *Mahāyugas*) and *Kalpas* (each equal to 14 *Manvantaras*), tending towards limitless time scales. Āryabhata 's cosmology was based on a *Mahāyuga* of 4,320,000 years consisting of four equal ages of 1,080,000 years each. Later astronomers kept the same value for the *Mahayuga*, but with the durations of the four ages following a decreasing series in ratios of 4: 3: 2: 1, probably to reflect the Puranic concept of progressive decrease of the truth: from the age of truth, *Satyayuga* or *Kritayuga*, to our current *Kaliyuga*, the numbers of years are now 1,728,000; 1,296,000, 864,000 and 432,000 (thus a *Mahāyuga* became ten times as long as a *Kaliyuga*). A 'day of Brahma' was equal to 1,000 *Mahayugas*, that is, 4,320,000,000 or 4.32 billion years; adding a night of equal duration, we reach 8.64 billion years; the number that so fascinated the US astronomer Carl Sagan because its order of magnitude is comparable to the age of our universe.[10] In fact, Brahma's entire life adds up to 311,040 billion human years, which yet represents 'no more than zero in the stream of infinity'.[11] Ultimately, 'time is without beginning and end,' as Āryabhata put it.[12] The concept of cyclic dissolutions (*Pralaya*) and new creations is also reminiscent of the 'pulsating universe' today's astronomers sometimes speak of.

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Of course, it would be an error to take figures of the durations of the four ages literally: as their perfect ratios show, they are clearly meant to be symbolic. With modern humans hardly more than 100,000 years old, this extraordinary cosmogony does not match our evolutionary history as we know it. So once again, we may ask what was the use of it all. One simple answer is, to keep pushing back limits.

Let us compare with Judeo–Christian Europe's belief that the creation came into existence just a few thousand years ago, for the first and last time: that was in *anno mundi*, the 'year of the world' 3761 BCE, according to rabbinical calculations prevalent from the tenth century onward. In the seventeenth century, Archbishop James Ussher revised those calculations and proposed that the universe had been created in 4004 BCE, a belief which prevailed until Darwin (and still prevails among a few fundamentalist Christian sects). Clearly, when we compare with the Indian concepts, we are dealing not only with different time scales, but with different *mind scales.*

This is also reflected in a search for the dimensions of the universe: Āryabhata provides us with an intriguing statement that the 'circumference of the sky' is 12,474,720,576,000 *yojanas*.[13] This works out to a sphere over 4,600 times the size of our solar system[14]—not by any means a small place. But what does this 'orbit of the sky' actually mean? Āryabhata's commentator, Bhāskara I, explains: 'For us, the sky extends to as far as it is illumined by the rays of the Sun. Beyond that, the sky is immeasurable. ... The sky is beyond limit; it is impossible to state its measure.'[15] So, infinity in time and space.

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The living presence of infinity takes on a deeper perspective when we consider Āryabhata's still more intriguing remark given at the end of a series of instructions for working out planetary orbits: 'Knowing ... the motion of the Earth and the planets on the celestial sphere, one attains the supreme Brahman after piercing through the orbits of the planets and stars.'[16] This unusual thought, quite unexpected in a highly concise text of astronomy and mathematics, suggests that, to him, the ultimate objective of astronomy was spiritual. Indian scientists of his age appear to have regarded the physical and the spiritual infinities as one and the same.

The Infinitesimal

Infinity is not found only at the colossal end of things: we find it at the other end, the infinitesimal. Thus the *paramānu*, or 'supreme atom', corresponded either to a length of about 0.3 nanometre or to a weight of 0.614 microgram.[17] We saw the infinite scale of *yugas*, but at the other end of it, in his *Siddhānta Shiromani*, Bhāskarāchārya defines the *nimesha* (literally, the blink of an eye) as one 972,000th of a day, or about 89 milliseconds, and went on to divide it further and further till he reached the *truti*, a unit of time equal to one 2,916,000,000th of a day—or about 30 microseconds.[18] The *Charaka Samhita*, one of Ayurveda's foundational texts, defines many units of weight, beginning with the *dhvamshī* which is about 0.12 mg.

Of what earthly use could such unearthly units of time, length or weight have been to the ancients?

Another kind of statement is almost disturbing. We find this very sensible observation in the *Mahābharāta* in a long argument against ahimsa:

> When the earth is ploughed, numberless creatures lurking in the ground are destroyed. ... Fish preys upon fish, various animals prey upon other species, and some species even prey upon themselves. ... The earth and the air all swarm with living organisms which are unconsciously destroyed by men from mere ignorance. *Ahimsa* was ordained of old by men who were ignorant of the true facts. There is not a man on the face of the earth who is free from the sin of doing injury to creatures.[19]

The argument is cogent, but how did its author know that that the air 'swarms with living organisms'? The *Ashtangahridayasamhita*, another text of Ayurveda, refers to blood corpuscles that are 'circular, legless, invisible, and coppery in colour'[20]—strangely reminiscent of red blood cells. Since the microscope was still centuries away, we must ask whether the authors of these texts had other means of reaching such 'scientific' knowledge.

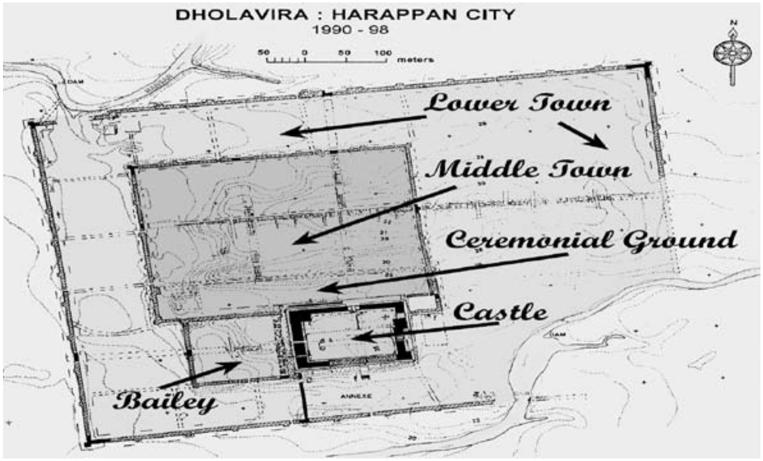
The *Ashtangahri-dayasamhita*, another text of Ayurveda, refers to blood corpuscles that are ' circular, legless, invisible, and coppery in colour' —strangely reminiscent of red blood cells.

Between the Two Infinities: Taming the Universe

However fascinating the two ends of infinity may be, there remains a good deal in between that calls for our attention. How did the ancients deal with it? A better question would be, how did they put some order in this apparent chaos?

First, by organizing space. It is striking that this need is reflected right from the beginnings of Indian civilization—in the town planning of Harappan cities. Let us visit Dholavira, in the Rann of Kachchh. Its strict plan is marked by multiple enclosures and a triple layout (Fig. 3): an acropolis or upper town consisting of a massive 'castle' located on the city's high point and an adjacent 'bailey'; a middle town, separated from the acropolis by a huge ceremonial ground; and a lower town, part of which was occupied by a series of reservoirs.

A mere look at the plan suggests a complex conceptual background. Can we make some sense of the concepts and rules Dholavira's urban architects followed? R.S.

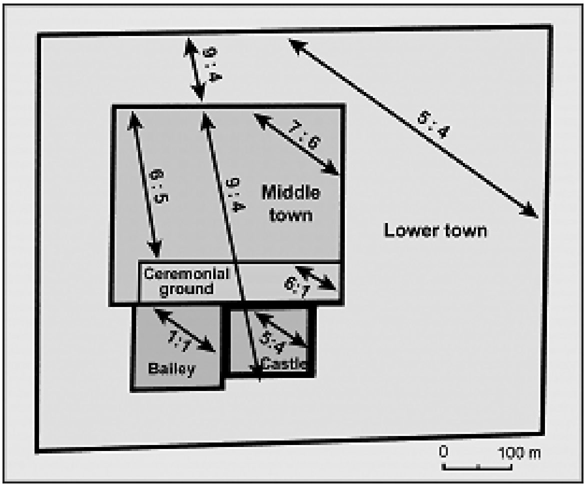


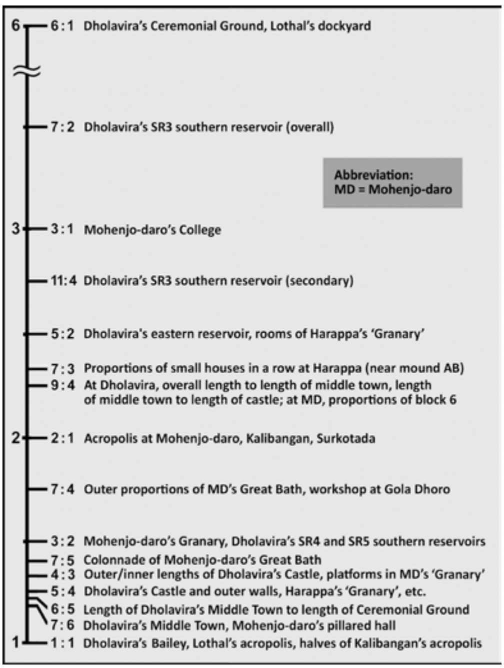
Bisht, who directed the excavations there, soon noticed that the city's dimensions obeyed precise proportions between their lengths and their breadths. He highlighted some of them, and my own research added a few; the following table (and Fig. 4) summarizes the principal ratios at work, along with their margin of error when compared with the actual dimensions (a very low margin, well below 1 per cent on average):

Such proportions are not limited to Dholavira: I have shown that they are found at many other Harappan sites and structures. Fig. 5 summarizes some of them.

Dimensions	Ratio	Margin of error (%)
Entire city*	**5 : 4**	0.0
"Castle", inner*	**5 : 4**	0.9
"Castle", outer*	**5 : 4**	2.4
"Bailey"*	**1 : 1**	0.0
Middle town*	**7 : 6**	0.5
Ceremonial ground*	**6 : 1**	0.7
Castle's outer to inner lengths**	**4 : 3**	0.7
Middle town's length to castle's internal length**	**3 : 1**	0.4
Middle town's length to castle's outer length**	**9 : 4**	0.2
City's length to middle town's length**	**9 : 4**	0.6
Middle town's length to ceremonial ground's length**	**6 : 5**	0.3
* = proposed by R.S. Bisht ** = proposed by Michel Danino		

Why impose such proportions on the ground when they serve no clear practical purpose? On a cultural level, the presence of carefully proportioned fortifications or buildings or reservoirs might be as much a specific cultural trait of the Harappan

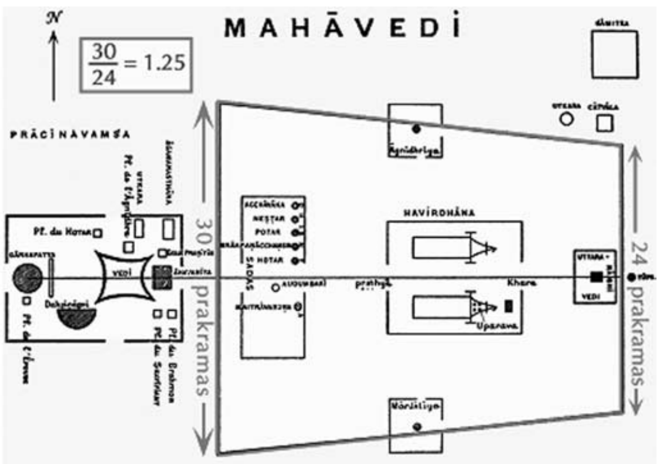




mind as pyramids were to Egypt or ziggurats to Mesopotamia. Here, instead of erecting colossal buildings, enormous energy was spent on defining space: a space for the rulers and administrators (the acropolis), as a symbol of authority, and a space for other classes of citizens (the urban space). Considerations of auspiciousness—as will be the case in later Hindu architecture—may also have played a part, as would have the notion of *increase*: Dholavira's overall proportions, 5 : 4, reflect a rate of increase of 25 per cent compared to a perfect square, a ratio repeated at the city's 'Castle' (inner and outer).

Defining space is also a vital need in the *Rig-Veda*. The *Ribhus* (divine builders) 'measured the sacrificial altar with a rod, as if it were a field' (1.110.5) while Vishnu 'measured out the earthly regions' (1.154.1). We find the same concept of measuring space (inner or outer) in the *mahavedi*, the Vedic sacrificial ground (Fig. 6). Its main area, in the form of a trapezoid, measures 24 units on its eastern side and 30 on the western, reflecting an increase which is the whole aim of the sacrifice—if we take it at a crude level, an increase in wealth, progeny, etc., but at a deeper level, an increase that results from our calling the gods to take birth in us, in the language of the *Rig-Veda*. Interestingly, the rate of increase, 30 : 24, reduces to 5 : 4, which is also Dholavira's master ratio.

The four altars before which the *purohit* as well as the sacrificer and his wife are seated, are in a separate enclosure on the western side. They are: (1) the *gārhapatya*



vedi, representing the earth and therefore circular; (2) at the other end, the *āhavaniya vedi* for the sky, and therefore square (because of the four cardinal directions); (3) in between, the *darshapurnamāsa* or *antar vedi*, that is, 'new moon – full moon' or 'in between' (the intermediary world in which the moon and other celestial bodies move); (4) finally, on the southern side, the *dakshinagni* for offerings to the ancestors. In other words, the *mahavedi* is nothing but a miniature representation of the cosmos; for a true sacrifice can only be cosmic in character: it is ultimately a repetition of Prajāpati's initial sacrifice, in which gods and poets sacrificed him and each part of his body became a part of the world. 'The gods sacrificed the sacrifice to the sacrifice' (*Rig-Veda*, 10.90).

Later, the construction of more elaborate altars of specific dimensions and shapes was expounded in the *Shulba Sutras*, texts of geometry usually dated to the sixth or eighth century BCE. The altar's base unit is the *purusha* or the human body, reflecting the equivalence between macrocosm and microcosm and creating a bridge between the universe and the human being. Indeed, most altars have five layers corresponding to the earth (at the bottom), the highest heaven (on top) and three intermediary worlds. A brick construction is nothing but a metaphor for the entire universe.

From Philosophy to Science

After the *Shulba Sūtras*, several philosophical systems attempted to put some order in this material world of ours, in particular the *Sāmkhya*, the *Vaisheshika* and the *Nyāya*. That they were no mere speculative recreations is made clear by their applications in *Ayurveda* and chemistry, among other fields.

- A brief look at some of the perceptions of matter propounded by *Kanāda* (*kana* = particle or atom), the legendary founder of the Vaisheshika system, which took shape between the sixth and the third centuries BCE, reveals surprisingly 'modern' notions:
- Atoms are 'globular' (*parimandala*) building blocks, forming dyads, triads, etc., in association with seventeen qualities (*guna*); atoms can change from one form to another, and the universe is an endlessly changing pattern of atoms. This reflects the fact that all matter can be reduced to a few building blocks, and only varying properties create the diversity of our world.

- Heating such a combination breaks it up: this is indeed correct.
- Matter exists in four states: solid, liquid, gas, ether. (Modern physics uses plasma in place of ether.)
- Heat and light consist of high-velocity particles. Indeed they do, heat being caused by the agitation of atoms and molecules, and light by the motion of photons.

In other words, the *mahavedi* is nothing but a miniature representation of the cosmos; for a true sacrifice can only be cosmic in character:

- 'Sounds are always produced in a series, like a series of ripples in water and when these waves reach the ear we hear them,' state the *Vaisheshika Sutras* quite correctly.
- The same text discusses motion and impetus (of various types), gravity, fluidity, conjunction, impact....

If those notions did not crystallize into a discipline we could call 'physics', it is, in part, because the required mathematical apparatus did not yet exist. Nevertheless we may note that ancient Indian savants were able to visualize some of our modern notions with a fair degree of precision.

Chemistry, which was inseparable from what we today call alchemy, was partly founded on Tantric concepts. The very name of the discipline—*rasāshastra* or *rasavidyā*—comes from *rasa*, which means essence, taste, sap, juice, semen, nectar, but also mercury. In Tantric symbolism, mercury was regarded as the male principle (Shiva) and supposed to give occult powers. Its complementary principle was sulphur, equated to the female principle (*Shakti*). Indeed, texts of alchemy often unfold in the form of a dialogue between Shiva and Shakti, and the origin of those two substances and others such as lead, mica, etc., was explained mythologically.

Again, this line of inquiry was not purely 'mythological' since it resulted in quite down-to-earth preparations in Ayurvedic and Siddha medical systems: for instance, mercury-based preparations for long life and vigour (after mercury had undergone up to eighteen complex processes so as to reach non-toxic compounds).

Is There an Indian Way of Doing Science?

This question is the title of a paper by A.V. Balasubramaniam, an expert in India's traditional knowledge systems.[21] Balasubramaniam rejects the colonial notion that the pursuits I have surveyed so far—ancient Indian science, if we may call it that—was elitist, restricted to a few upper castes and ignored by the mass of the population. On the contrary, he finds a knowledge-based society:

> Theoretical knowledge, theories and principles are not meant to be reposed in a small number of experts, institutions or texts, but are created and shared on a wide scale, even by the ordinary folk who are the day to day practitioners of the arts and sciences.[22]

This is especially visible in disciplines such as metallurgy or medicine. They sought to integrate folk wisdom, and invariably favoured experience over theory: from the parameters of an eclipse to a particular treatment, the theory was expected to adapt itself to facts and not the other way round.

This pragmatism was so strong that we find in ancient India little interest in 'absolute' laws or rules or in axiomatic foundations of the kind favoured by classical Greece. In astronomy and mathematics, for instance, Indians showed great skill at developing efficient algorithms, whether it was to solve Diophantine equations (i.e., for solutions in integers only) or to predict the occurrence of eclipses. Many of those algorithms were later transmitted to Europe through the Arabs.

However, the criticism often made by Western historians of science that Indian savants had no notion of a 'proof' is unjustified. As M.D. Srinivas has argued in a series of papers[23] if proofs often appear to be absent from classical texts (such as the *Aryabhatīya*) it is mostly because of their very nature as summaries of results. We do find the notion of rationale or proof (*upapatti*) in the works of Govindasvāmin (c. 800 CE), Bhāskarāchārya (twelfth century), and more so, in commentaries (e.g., Jyesthadeva's *Yuktibhāshā* of 1530 CE).

Taking stock, Indian science, rooted in Indian thought and belief systems, contributed much that was later integrated in what we call 'modern science'. And although it is true that no astronomer today would use Āryabhata's astronomy or no geologist would turn to the *Brihat Samhita*, there is still much benefit to be drawn from traditional technologies and systems: architecture, medicine and agriculture are shining examples of this neglected truth, but so is metallurgy, as the late R. Balasubramaniam showed in his studies of 'India's rust-resistant iron pillars.[24]

At a more vitally urgent level, traditional attitudes can still contribute crucial alternatives to current lifestyles and economic systems. The British economist E.F. Schumacher warned:

> [In] Buddhist economics, since consumption is merely a means to human well-being, the aim should be to obtain the maximum of well-being with the minimum of consumption.... The less toil there is, the more time and strength is left for artistic creativity. Modern economics, on the other hand, considers consumption to be the sole end and purpose of all economic activity.[25]

The Paradox of Knowledge

In the end, we remain confronted with the paradox at the heart of all quest for knowledge. In its *Hymn to the Creation*, the *Rig-Veda* wonderfully expressed the first member of the paradox—the ultimate mystery of this universe:

Darkness hidden by darkness in the beginning was this all, an ocean without consciousness ... out of it the One was born by the greatness of Its energy.

The Masters of Wisdom found out in the non-existent that which builds up the existent. Their ray was extended horizontally; there was something above, there was something below. ...

Who verily knows and who can here declare it, from where it was born and from where this creation came?

He, the first origin of this creation, whether he formed it all or did not form it, whose eye controls this world in highest heaven, he verily knows it—or perhaps he knows not.[26]

Let us hope he does, however. But despite this impossibility of knowing, if we rise high enough above the prison of the human mind, we come to a point where

yasmin vijñāte sarvam idam vijñātam
That which being known, all is known[27]

It does look as if early Indian savants were, at times, able to reach out to that peak of human consciousness. Perhaps that is what Āryabhata meant when he spoke of reaching the supreme Brahman 'after piercing through the orbits of the planets and stars'.

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12. K.S. Shukla and K.V. Sarma (eds.), *Āryabhatīya of Āryabhata* (New Delhi: Indian National Science Academy, 1976, III.11).
13. This number is obtained by multiplying the number of revolutions of the Moon in a *yuga* of 4,320,000 years, which Āryabhata tells us is 57,753,336, by 12 and again by 30, 60 and 10 (*Āryabhatīya of Āryabhata*, op. cit., I.6).
14. Āryabhata's *yojana* is about 13.6 km; 12,474,720,576,000 *yojanas* is therefore 17 10^{13} km, which yields a diameter of roughly 5.4 10^{13} km. The diameter of Pluto's orbit (if we take the solar system to mean up to Pluto) is 1.18 10^{10} km.

15. Quoted by K.S. Shukla and K.V. Sarma in *Āryabhatīya of Āryabhata*, op. cit., p. 12.
16. *Āryabhatīya of Āryabhata,* op. cit., I.13.
17. According to Georges Ifrah, *The Universal History of Numbers,* op. cit., vol. 2, p. 139. (My calculation of the *paramānu's* length would be slightly different, but that would hardly change the order of magnitude of the result.)
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27. *Shāndilya Upanishad, 2.2.*

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