

Greek and Indian Cosmology: Review of Early History

Subhash Kak*

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1 Introduction

Greek and Indian traditions have profoundly influenced modern science. Geometry, physics, and biology of the Greeks; arithmetic, algebra, and grammar of the Indians; and astronomy, philosophy, and medicine of both have played a key role in the creation of knowledge. The interaction between the Indians and the Greeks after the time of Alexander is well documented, but can we trace this interaction to periods much before Alexander's time so as to untangle the earliest connections between the two, especially as it concerns scientific ideas?

Since science is only one kind of cultural expression, our search must encompass other items in the larger matrix of cultural forms so as to obtain a context to study the relationships. There are some intriguing parallels between the two but there are also important differences. In the ancient world there existed much interaction through trade and evidence for this interaction has been traced back to the third millennium BC, therefore there was sure to have been a flow of ideas in different directions.

The evidence of interaction comes from the trade routes between India and the West that were active during the Harappan era. Exchange of goods was doubtlessly accompanied by an exchange of ideas. Furthermore, some

*Louisiana State University, Baton Rouge, LA 70803-5901, USA, Email: kak@ece.lsu.edu

communities migrated to places away from their homeland. For example, an Indian settlement has been traced in Memphis in Egypt based on the Indic themes of its art.¹ The Indic element had a significant presence in West Asia during the second millennium BC and later.² Likewise, Greek historians accompanying Alexander reported the presence of Greek communities in Afghanistan.³

In view of these facts, the earlier view of the rise in a vacuum of Greek science cannot be maintained.⁴ Indian science must have also benefited from outside influences.

The indebtedness of the Greeks to the Babylonians and the Egyptians is now acknowledged, thanks to the decipherment of the Babylonian tablets of the second millennium BC. The first flowering of Greek philosophy took place in Miletus, a trading centre of the Ionian Greeks on the Asiatic coast, where Greek and Asiatic cultures mingled. In addition to the Babylonians antecedents of Greek science there existed Indian antecedents.

In the desire amongst Eurocentric historians to trace science and philosophy to Greece alone so that somehow it would then appear as something uniquely “Western,” the question of the Asiatic basis to Greek science and philosophy the Asian prehistory of Western science is ignored. More recently there is grudging acknowledgement that the Babylonians and the Egyptians may have contributed to the ideas.⁵

It is instructive to begin with the similarities in the Greek and Indian sciences of the late first millennium BC. Specifically, I shall consider the similarities in geometry, astronomy, and medicine.

In geometry, it is striking that the same type of constructions are used in the Śulbasūtras and by Euclid to prove the Theorem of Pythagoras.⁶ In astronomy, the size assumed for the solar system is very similar and the planetary orbits are explained based on retrograde motions.⁷ In medicine, Plato speaks of three humours with a central role to the idea of breath (*pneuma*), when a similar three-doṣa system around breath (*prāṇa*) is already a feature of the much older Vedic thought.⁸

These commonalities have led to four different kind of theories:

1. Viewing the Indian evidence as being later than the earliest occurrence in Greece. This notion was used by some 19th century European scholars to date Indian texts.⁹

2. Showing a common earlier origin for the two sciences outside of India and Greece, perhaps as the common heritage of the Indo-Europeans. More recently, this common source has been seen in Central Asia.¹⁰
3. Showing that evidence exists for the priority of Indian sciences over the corresponding Greek sciences.¹¹
4. A theory of essential independent origin for the sciences in India and Greece although some general ideas may have been carried through trade caravans from one region to another.¹²

I shall now take each one of these views separately. Before I proceed I would like to emphasize that the objective of this essay is not to show the priority of Indian science. In fact, my own position favours the fourth theory in the list above.

Scientific developments occur as a consequence of certain social and material conditions. It is because of India's early urbanization that many Indian scientific innovations occurred at a time that predates the early Greek scientific age. But it does not follow that the Indian innovations were directly linked to the corresponding innovations in Greece.

I shall begin by providing the essentials of the Indic world-view which highlights its points of difference with the Greek world-view. This is important to define the context in which a relationship between the two may be examined. I shall, in particular, make the comparisons both in regard to abstract theory as in mathematics and astronomy and in experiment and observation as in medicine. My selection of topics is not exhaustive since my objective is to point to issues of difference (as in astronomy) and that of similarity (medicine).

2 Indian science and its cosmology

Indian archaeology and literature provides us with considerable layered evidence related to the development of science. The chronological time frame for this history is provided by the archaeological record which has been traced in an unbroken tradition to about 8000 BC. Prior to this we have records of rock paintings that are believed to be considerably older. The earliest textual source is the Rig Veda which is a compilation of very early material.

There are astronomical references in this and the other Vedic books which recall events in the third or the fourth millennium BC and earlier. The discovery that Sarasvati, the preeminent river of the Rig Vedic times, went dry around 1900 BC due to tectonic upheavels supports the view that the Rig Veda hymns recall events dated prior to this epoch. According to traditional history, Rig Veda is prior to 3100 BC. The astronomical evidence related to winter solstices shows a layered chronology of early Indian texts from the third to the first millennia BC.¹³

Indian writing (the so-called Indus script) goes back to the beginning of the third millennium BC but it has not yet been deciphered. However, statistical analysis shows that Brāhmī (of which earliest records have been traced to 550 BC in Sri Lanka) evolved out of this writing. The invention of the symbol for zero appears to have been made around 50 BC to 50 AD.¹⁴

Vedic cosmology

Briefly, the Vedic texts present a tripartite and recursive world view. The universe is viewed as three regions of earth, space, and sky which in the human being are mirrored in the physical body, the breath (prāṇa), and mind. The processes in the sky, on earth, and within the mind are taken to be connected. The universe is also connected to the human mind, leading to the idea that introspection can yield knowledge. The universe goes through cycles of life and death.

The Vedic seers were aware that all descriptions of the universe lead to logical paradox. The one category transcending all oppositions is *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 conception. The notable features of this world view are:

1. *An Extremely Old and Large Cyclic Universe:* The Vedas speak of an infinite universe, and the Brāhmaṇas (e.g. Pañcaviṃśa) mention very large yugas. 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 Purāṇas speak of the universe going through cycles of creation and destruction of 8.64 billion years, although there are longer cycles as well.

2. *An Atomic World and the Subject/Object Dichotomy:* According to the atomic doctrine of Kaṇāda, there are nine classes of substances: ether, space, and time that are continuous; four elementary substances (or particles) called earth, air, water, and fire that are atomic; and two kinds of mind, one omnipresent and another which is the individual. As in the systems of Sāṃkhya and Vedānta, a subject/object dichotomy is postulated. The conscious subject is separate from the material reality but he is, nevertheless, able to direct its evolution. The atomic doctrine of Kaṇāda is much more interesting than that of Democritus.
3. *Relativity of Time and Space:* That space and time need not flow at the same rate for different observers is encountered in the Brāhmaṇa and Purāṇa stories and in the Yoga Vāsiṣṭha. Obviously, we are not speaking here of the mathematical theory of relativity regarding an upper limit to the speed of light, yet the consideration of time acting different to different observers is quite remarkable.

Here's a passage on anomalous flow of time from the Bhāgavata Purāṇa:¹⁵

“Taking his own daughter, Revati, Kakudmi went to Brahmā in Brahmāloka, and inquired about a husband for her. When Kakudmi arrived there, Brahmā was engaged in hearing musical performances by the Gandharvas and had not a moment to talk with him. Therefore Kakudmi waited, and at the end of the performance he saluted Brahmā and made his desire known. After hearing his words, Brahmā laughed loudly and said to Kakudmi, ‘O King, all those whom you may have decided within the core of your heart to accept as your son-in-law have passed away in the course of time. Twenty-seven caturyugas have already passed Those upon whom you may have decided are now gone, and so are their sons, grandsons. and other descendants. You cannot even hear about their names.’”

4. *Evolution of Life:* The Mahābhārata (pre-400 BC) and the Purāṇas have a chapter on creation and the rise of mankind. It is said that man arose at the end of a chain where the beginning was with plants and various kind of animals. Here's the quote from the Yoga Vāsiṣṭha:¹⁶ “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 (four million earth years) the earth was covered by

lava. Then demons (asuras) ruled the earth; they were deluded and powerful. The earth was their playground. 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 (4 million earth years) the earth was covered with the corpses of the asuras.”

Vedic evolution is not like Darwinian evolution; it has a different focus. The urge to evolve into higher forms is taken to be inherent in nature. A system of an evolution from inanimate to progressively higher life is taken to be a consequence of the different proportions of the three basic attributes of sattva, rajas, and tamas.

The doctrine of the three constituent qualities plays a very important role in the Sāṃkhya physics and metaphysics. In its undeveloped state, cosmic matter has these qualities in equilibrium. As the world evolves, one or the other of these become preponderant in different objects or beings, giving specific character to each.

5. *A Science of Mind, Yoga:* Inner science, described in the Vedic books and systematized by Patañjali in his Yoga-sūtras is a very sophisticated description of the nature of the human mind and its capacity. It makes a distinction between memory, states of awareness, and the fundamental entity of consciousness. It puts the analytical searchlight on mind processes, and it does so with such clarity and originality that it continues to influence people all over the world.

Several kinds of yoga are described. They provide a means of mastering the body-mind connection. Indian music and dance also has an underlying yogic basis.

6. *Binary Numbers, Infinity:* A binary number system was used by Piṅgala¹⁷ (450 BC, if we accept the tradition that he was Pāṇini's brother) to represent Vedic metres. The structure of this number system may have helped in the invention of the sign for zero. Without this sign, mathematics would have languished. It is of course true that the binary number system was independently invented by Leibnitz in 1678, but the fact that the rediscovery had to wait almost 2,000 years only emphasizes the originality of Piṅgala's idea.

The idea of infinity is found in the Vedas itself. It was correctly understood as one where addition and subtraction of infinity from it leaves it unchanged.

7. *A Complete Grammar, Limitation of Language:* The Aṣṭādhyāyī, the grammar of the Sanskrit language by Pāṇini (450 BC), describes the entire language in 4,000 algebraic rules. The structure of this grammar contains a meta-language, meta-rules, and other technical devices that make this system effectively equivalent to the most powerful computing machine.¹⁸ No grammar of similar power has yet been constructed for any other language. The famous American scholar Leonard Bloomfield called Pāṇini's achievement as "one of the greatest monuments of human intelligence."

The other side to the discovery of this grammar is the idea that language (as a formal system) cannot describe reality completely. This limitation of language is why reality can only be experienced and never described fully.

Many aspects of the Indian scientific system have parallels in modern science. Indian ideas have found special resonance amongst theoretical physicists and psychologists.

Knowledge was classified in two ways: the lower or dual; and the higher or unified. The seemingly irreconcilable worlds of the material and the conscious were taken as 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. This led to the groups of: logic (Nyāya) and physics (Vaiśeṣika), cosmology (Sāṃkhya) and psychology (Yoga), and language (Mīmāṃsā) and reality (Vedānta). Although these philosophical schools were formalized in the post-Vedic age, we find the basis of these ideas in the Vedic texts.

The Sāṃkhya and the Yoga systems take the mind as consisting of five components: manas, ahaṃkāra, citta, buddhi, and ātman. Manas is the lower mind which collects sense impressions. Ahaṃkāra 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 ahaṃkāra, their evaluation and resulting decisions are arrived at by buddhi, the intellect.

Citta is the memory bank of the mind. These memories constitute the foundation on which the rest of the mind operates. But citta 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 surrounding the innermost aspect of consciousness is the ātman, the self, or brahman.

Logic

The objective of the Nyāya is anvīkṣikī, or critical inquiry. The beginnings of it go into the Vedic period, but its first systematic elucidation is due to Gautama in his Nyāya Sūtra dated to 3rd century BC. The text begins with the nature of doubt and the means of proof. Next it considers self, body, senses and their objects, cognition and mind. It describes the cognizing human in terms of volition, sorrow, suffering and liberation. The most important early commentary on this text is the Nyāya Bhāṣya of Vātsyāyana.

The Nyāya is also called pramāṇa śāstra or the science of correct knowledge. Knowing is based on four conditions: 1) The subject or the pramātrī; 2) The object or the prameya to which the process of cognition is directed; 3) The cognition or the pramiti; and 4) the nature of knowledge, or the pramāṇa.

The Nyāya system supposes that we are so constituted so as to seek truth. Our minds are not empty slates; the very constitution of our mind provides some knowledge of the nature of the world. The four pramāṇas through which correct knowledge is acquired are: pratyakṣa or direct perception, anumāna or inference, upamāna or analogy, and śabda or verbal testimony.

The function of definition in the Nyāya is to state essential nature (svarūpa) that distinguishes the object from others. Three fallacies of definition are described: ativyāpti, or the definition being too broad as in defining a cow as a horned animal; avyāpti, or too narrow; and asambhava, or impossible.

Gautama mentions that four factors are involved in direct perception: the senses (indriyas), their objects (artha), the contact of the senses and the objects (sannikarṣa), and the cognition produced by this contact (jñāna). The five sense organs, eye, ear, nose, tongue, and skin have the five elements light, ether, earth, water, and air as their field, with corresponding qualities of colour, sound, smell, taste and touch.

Manas or mind mediates between the self and the senses. When the

manas is in contact with one sense-organ, it cannot be so with another. It is therefore said to be atomic in dimension. It is because of the nature of the mind that our experiences are essentially linear although quick succession of impressions may give the appearance of simultaneity.

Objects have qualities which do not have existence of their own. The color and class associated with an object are secondary to the substance. According to Gautama, direct perception is inexpressible. Things are not perceived as bearing a name. The conception of an object on hearing a name is not direct perception but verbal cognition.

Dharmakīrti, a later Nyāya philosopher, recognizes four kinds of perception: sense-perception, mental perception (manovijñāna), self-consciousness, and yogic perception. Self-consciousness is a perception of the self through its states of pleasure and pain. In yogic perception, one is able to comprehend the universe in fullness and harmony.

Not all perceptions are valid. Normal perception is subject to the existence of 1) the object of perception, 2) the external medium such as light in the case of seeing, 3) the sense-organ, 4) the mind, without which the sense-organs cannot come in conjunction with their objects, and 5) the self. If any of these should function improperly, the perception would be erroneous. The causes of illusion may be doṣa (defect in the sense-organ), samprayoga (presentation of only part of an object), or saṃskāra (habit based on irrelevant recollection).

Anumāna (inference) is knowledge from the perceived about the unperceived. The relation between the two may be of three kind: the element to be inferred may be the cause or the effect of the element perceived, or the two may be the joint effects of something else.

The Nyāya syllogism is expressed in five parts: 1) pratijñā, or the proposition: the house is on fire; 2) hetu, or the reason: the smoke; 3) udāharaṇa, the example: fire is accompanied by smoke, as in the kitchen; 4) upanaya, the application: as in kitchen so for the house; 5) nigamana, the conclusion: therefore, the house is on fire. This recognizes that the inference derives from the knowledge of the universal relation (vyāpti) and its application to the specific case (pakṣadharmatā). There can be no inference unless there is expectation (ākāṅkṣā) about the hypothesis which is expressed in terms of the proposition.

The minor premise (pakṣadharmatā) is a consequence of perception, whereas the major premise (vyāpti) results from induction. But the universal propo-

sition cannot be arrived at by reasoning alone. Frequency of the observation increases the probability of the universal, but does not make it certain.

The Nyāya system lays stress on antecedence in its view of causality. But both cause and effect are viewed as passing events. Cause has no meaning apart from change; when analyzed, it leads to a chain that continues without end. Causality is useful within the limits of experience, but it cannot be regarded as of absolute validity. Causality is only a form of experience. The advancement of knowledge is from upamāna, or comparison, with something else already well known. This leads us back to induction through alaukika pratyakṣa at the basis of the understanding.

Śabda, or verbal testimony, is a chief source of knowledge. The meaning of words is by convention. The word might mean an individual, a form, or a type, or all three. A sentence, as a collection of words, is cognized from the trace (saṃskāra) left at the end of the sentence. Knowledge is divided into cognitions which are not reproductions of former states of consciousness (anubhava) and those which are (smṛti). Memory is said to arise from a contact of the ātman with the manas and the trace left by the previous experience. The impression is the immediate cause of the recollection, whereas recognition of identity requires an inductive leap.

The Nyāya speaks of errors and fallacies arising by interfering with the process of correct reasoning. The Nyāya attacks the Buddhist idea that no knowledge is certain by pointing out that this statement itself contradicts the claim by its certainty. Whether cognitions apply to reality must be checked by determining if they lead to successful action. Pramā, or valid knowledge, leads to successful action unlike erroneous knowledge (viparyaya).

The Nyāya accepts the metaphysics of the Vaiśeṣika. It is asserted that the universe has certain elements that are not corporeal. The subjective cognitions and feelings which are part of the individual's consciousness are transitory and, therefore, they cannot be associated with substances. They are viewed as qualities associated with the ātman.

Physics and chemistry

In the Vaiśeṣika system atoms combine to form different kinds of molecules which break up under the influence of heat. The molecules come to have different properties based on the influence of various potentials (tanmātras).

Heat and light rays are taken to consist of very small particles of high

velocity. Being particles, their velocity is finite. The gravitational force is perceived as a wind. The other forces are likewise mediated by atoms of one kind or the other.

Indian chemistry developed many different alkalis, acids and metallic salts by processes of calcination and distillation, often motivated by the need to formulate medicines. Metallurgists developed efficient techniques of extraction of metals from ore.

Geometry and mathematics

Indian geometry began very early in the Vedic period in altar problems as in the one where the circular altar (earth) is to be made equal in area to a square altar (heavens). Two aspects of the “Pythagoras” theorem are described in the Śulbasūtra texts by Baudhayana and others. The geometric problems are often presented with their algebraic counterparts. The solution to the planetary problems also led to the development of algebraic methods.

Astronomy

Using hitherto neglected texts, an astronomy of the third millennium BC has been discovered recently. Yājñavalkya (1800 BCE ?) knew of a 95-year cycle to harmonize the motions of the sun and the moon and he also knew that the sun’s circuit was asymmetric.

Astronomical numbers played a central role in Vedic ritual.¹⁹ Part of the ritual was to devise geometrical schemes related to the lengths of the solar and the lunar years. The organization of the Vedic books was also according to an astronomical code. To give just one example, the total number of verses in all the Vedas is 20,358 which equals 261×78 , a product of the sky and atmosphere numbers of Vedic ritual!

The second millennium text Vedāṅga Jyotiṣa of Lagadha 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. An epicycle theory was used to explain planetary motions. Later theories consider the motion of the planets with respect to the sun, which in turn is seen to go around the earth.

The cosmological descriptions of the Purāṇas are somewhat confusing. Their objective is to describe the inner cosmos of the individual in a manner

that parallels the outer cosmos. With the earth taken to be at the level of the navel with concentric continents around the central axis (spine), the sun and the moon are at the north in the head and the planets are viewed somewhat beyond. In this conception of the inner cosmos, the earth is taken to be 500 million yojanas (to be equated to the size of the human body) and the sun, as a center within the brain is a tiny 9,000 yojanas in length. The earth (the human body) is taken to rest on a turtle (the planet earth).

Medicine

Āyurveda, the Vedic system of medicine, views health as harmony between body, mind and soul. It deals not only with the body, but also with psychological and spiritual health. Its two most famous texts belong to the schools of Caraka and Suśruta. According to Caraka, health and disease are not predetermined and life may be prolonged by human effort. Suśruta defines the purpose of medicine to cure the diseases of the sick, protect the healthy, and to prolong life.

The beginnings of medicine may be traced to the Ṛgveda, since it speaks of the bhiṣaj, or physician, in connection with setting a broken bone. From other references the bhiṣaj or vaidya emerges as a healer of disease and expert in herbs. The twin gods Āśvins are particularly associated with healing of blindness, lameness, and leprosy. They give an artificial leg to a hero who has lost a leg in battle. They are also associated with rejuvenation. Soma is another healing deity. In many contexts, Indra, Agni, and Soma represent the three dhātus of air, fire and water. The Garbha Upaniṣad describes the body as consisting of five elements (with further groups of five as in Sāṃkhya), supported on six (the sweet, sour, salt, bitter, acid and harsh juices of food), endowed with six qualities, made up of seven tissues, three doṣas, and twice-begotten (through father and mother). It further adds that the head has four skull-bones, with sixteen sockets on each side. It says that the body has 107 joints, 180 sutures, 900 sinews, 700 veins, 500 muscles, 360 bones, and 45 million hairs.

According to the Praśna Upaniṣad, the number of veins is 727,210,201. There are 101 chief veins, each with 100 branch veins, to each of which are 72,000 yet smaller tributary veins. In Chāndogya Upaniṣad, organisms are divided into three classes based on their origin: born alive (from a womb), born from an egg, and born from a germ.

According to the tradition, there existed six schools of medicine, founded by the disciples of the sage Punarvasu Ātreya. Each of these disciples Agniveśa, Bhela, Jatūkarna, Parāśara, Hārīta, and Kṣārapāṇi composed a Saṃhitā. Of these, the one composed by Agniveśa was supposed to be the best. The Agniveśa Saṃhitā was later revised by Caraka and it came to be known as Caraka Saṃhitā. Āyurveda is traditionally divided into eight branches which, in Caraka's scheme are: 1. Sūtrasthāna, general principles; 2. Nidānasthāna, cause of disease; 3. Vimānasthāna, diagnostics; 4. Śarīrasthāna, anatomy and embryology; 5. Indriyasthāna, prognosis; 6. Cikitsāsthāna, therapeutics; 7. Kalpasthāna, pharmaceuticals; and 8. Siddhisthāna, successful treatment.

In the Caraka school, the first teacher was Bharadvāja, whereas in the Suśruta school, the first person to expound Āyurvedic knowledge was Dhanvantari in the form of the king Divodāsa. The Caraka and Suśruta Saṃhitā are compendiums of two traditions rather than texts composed by single authors. The beginnings of these traditions must go to the second millennium BC if not earlier because of the parallel information obtained in the Vedic Saṃhitā and the description in the Mahābhārata. There is much that is common in the two texts, except that the Suśruta Saṃhitā is richer in the field of surgery. Part of the original Caraka Saṃhitā is lost, and the current version has several chapters by the Kashmiri scholar Dṛḍhabala.

An attempt to reconcile the texts of Caraka and Suśruta was made by Vāgbhaṭa the Elder in second century BC in his Aṣṭāṅga Saṅgraha. The works of Caraka, Suśruta, and the Elder Vāgbhaṭa are considered canonical and reverentially called the Vṛddha Trayī, "the triad of ancients." Later, Vāgbhaṭa the Younger wrote the Aṣṭāṅga Hṛdaya Saṃhitā which is a lucid presentation of the Āyurveda giving due place to the surgical techniques of Suśruta. In the eighth century, Mādhava wrote his Nidāna, which soon assumed a position of authority.

Health in Āyurveda is considered to be a balance of the three doṣas or primary forces of prāṇa or vāta (air), agni or pitta (fire) and soma or kapha (water and earth). The five elements of the Sāṃkhya enumeration, that is earth, water, fire, air, and ether, in different combinations constitute the three body doṣas: vāta (air and ether), pitta (fire) and kapha (earth and water).

The tridoṣa or tridhātu theory of Āyurveda has sometimes been misunderstood to imply that vāta, pitta, and kapha literally mean air, bile, and

phlegm, which are the ordinary physiological meanings of the terms. In reality, vāta stands for the principle of motion, cell development in general, and the functions of the central nervous system in particular. Pitta signifies the function of metabolism, including digestion and formation of blood, various secretions and excretions which are either the means or the end product of tissue combustion. Kapha represents functions of cooling, preservation and heat regulation. The imbalance of these elements leads to illness. The predominance of one or the other represents different psychological types.

Each of the doṣas is recognized to be of five kinds. Vāta appears as prāṇa (governing respiration), udāna (for uttering sounds and speaking), samāna (for separating the digested juice), vyāna (carrying fluids including blood to all parts of the body), and apāna (expelling waste products). Pitta appears as pācaka (for digestion and imparting heat), rañjaka (imparting redness to the chyle and blood), sādhaka (increasing the power of the brain), ālocaka (strengthen vision), and bhrājaka (improve complexion). Kapha has kledaka (moists food), avalambaka (imparts energy and strength), bodhaka (enables tasting), tarpaka (governs the eye and other sensory organs), and śleṣmaka (acts as lubrication).

Every substance (animal, vegetable or mineral) is a dravya with properties in different proportions: rasa, guṇa, vīrya, vipāka, and prabhāva. The guṇas are qualities such as heat, cold, heaviness, lightness and so on in a total of twenty types. Of the twenty guṇas, heat (uṣṇa) and cold (śīta) are the most prominent. Vīrya is generative energy that may also be hot or cold.

Vipāka may be understood as the biochemical transformations of food whereas prabhāva is the subtle effect on the body of the substance. Food is converted into rasa by the digestive action of jāṭharāgni, the fire in the stomach. Rasas are six in number: madhura, āmla, lavaṇa, tikta, kaṭu, and kaṣāya. Each rasa is a result of the predominance of two elements and each is recognized by the taste. The knowledge of the rasas is important in therapeutics. Madhura, āmla and lavaṇa work well against vāta; madhura, tikta, and kaṣāya against pitta; and kaṭu and kaṣāya against kapha.

The five elements in various proportions are said to form seven kinds of tissue (dhātu). These are: rasa (plasma), rakta (blood), māmśa (flesh), medas (fat), asthi (bone), majjā (marrow), and śukra (semen). The activity of the dhātu is represented by ojas (vitality) or bala (strength). Ojas is mediated through an oily, while fluid that permeates the whole body. The functions of the vital organs like the heart, brain, spleen, and liver relate

to the flow and exchange of tissues. The heart is the chief receptacle of the three chief fluids of the body: rasa, rakta, and ojas.

The Bhela Saṃhitā, ancient like the Caraka and Suśruta Saṃhitā but available only in fragments, considers the brain to be the center of the mind. It distinguishes between manas (mind) with its seat in the brain and the citta, consciousness, with its seat in the heart.

Training a Vaidya

The Āyurvedic vaidya must master eight branches: kāyācikitsā (internal medicine), śalyacikitsā (surgery including anatomy), śālākyacikitsā (eye, ear, nose, and throat diseases), kaumarabhr̥tya (pediatrics), bhūtavidyā (psychiatry, or demonology), and agada tantra (toxicology), rasāyana (science of rejuvenation), and vājikaraṇa (the science of fertility).

In addition, the vaidya was expected to know ten arts that were considered indispensable in the preparation and application of medicines: distillation, operative skills, cooking, horticulture, metallurgy, sugar manufacture, pharmacy, analysis and separation of minerals, compounding of metals, and preparation of alkalis. The teaching of anatomy, physiology, pathology, microbiology, and pharmacology was done during the instruction of relevant clinical subjects. For example, teaching of anatomy was a part of the teaching of surgery, embryology was a part of training in pediatrics and obstetrics, and the knowledge of physiology and pathology was interwoven in the teaching of all the clinical disciplines.

The initiation ceremony of the physician was called upanayana and it involved the teacher leading the student three times around the sacred fire. This ceremony made the student thrice-born (trija), distinguished from the twice-born (dvija) non-physicians.

At the closing of the initiation, the guru gave a solemn address to the students where the guru directed the students to a life of chastity, honesty, and vegetarianism. The student was to strive with all his being for the health of the sick. He was not to betray patients for his own advantage. He was to dress modestly and avoid strong drink. He was to be collected and self-controlled, measured in speech at all times. He was to constantly improve his knowledge and technical skill. In the home of the patient he was to be courteous and modest, directing all attention to the patient's welfare. He was not to divulge any knowledge about the patient and his family. If the

patient was incurable, he was to keep this to himself if it was likely to harm the patient or others.

Suśruta speaks of a similar address to the initiates. In addition, the student was told to wear an ochre robe. The teacher also took an oath: “If you behave well and I fail to take care of you, that will be my sin and my learning will be of no avail.”

The normal length of the student’s training appears to have been seven years. Before graduation, the student was to pass a test. But the physician was to continue to learn through texts, direct observation (pratyakṣa), and through inference (anumāna). In addition, the vaidyas attended meetings where knowledge was exchanged. The doctors were also enjoined to gain knowledge of unusual remedies from hillsmen, herdsman, and forest-dwellers.

The qualified vaidya on his rounds from house to house was attended by an assistant who carried his bag of instruments and herbs. He was clad in white, shod in sandals, with a staff in hand, he had a servant follow him with a parasol. He would also see patients at his own house where he also had a storeroom with drugs and instruments. He compounded many of the drugs himself from herbs with the help of his assistant.

The vaidya was assisted by nurses (paricāraka). Suśruta lists the following qualities of the nurse: devotion and friendliness, watchfulness, not inclined to disgust, and knowledgeable to follow the instructions of the doctor.

There existed governmental control of the medical profession. Suśruta hints of this when he mentions that a quack kills people out of greed, because of the fault of the king. There is reference to free hospitals in ancient India.

Dissection and Surgery

Suśruta laid great emphasis on direct observation and learning through dissection (avagharṣana). In preparation of dissection the excrements of the selected dead body were cleaned. The body was now covered with a sheath of grass and left to decompose in the still waters of a pool. After seven days, the student was instructed to scrape off the skin and carefully observe the internal organs of the body.

Suśruta classified surgical operations into eight categories: incision (chedya), excision (bhedyā), scarification (lekhyā), puncturing (vedhyā), probing (esya), extraction (āhāryā), evacuation and drainage (viśrāvya), and suturing (sīvyā). Suśruta lists 101 blunt and 20 sharp instruments that were used in surgery,

instructing that these should be made of steel and kept in a portable case with a separate compartment for each instrument. Fourteen types of bandages were described. Surgical operations on all parts of the body were described. These include laparotomy, craniotomy, caesarian section, plastic repair of the torn ear lobule, cheiloplasty, rhinoplasty, excision of cataract, tonsillectomy, excision of laryngeal polyps, excision of anal fistule, repair of hernias and prolapse of rectum, lithotomy, amputation of bones, and many neurosurgical procduces.

Medications were used for pre-operative preparation and medicated oils were used for dressing of wounds. Ice, caustics and cautery were used for haemostasis. Medicated wines were used before and after surgery to assuage pain. A drug called sammohini was used to make the patient unconscious before a major operation and another drug, sañjivini, was employed to resuscitate the patient after operation or shock.

Diagnosis

It was enjoined that diagnosis be done using all five senses together with interrogation. The diagnosis was based on: 1. cause (nidāna); 2. premonitory indications (purvarūpa); 3. symptoms (rūpa); 4. therapeutic tests (upaśaya); and 5. the natural course of development of the disease (samprāpti). Suśruta declares that the physician (bhiṣaj), the drug (dravya), the nurse (paricāraka), and the patient (rogī) are the four pillars on which rest the success of the treatment.

Different methods of treatment, based on the diagnosis of the patient, were outlined. The drugs were classified into 75 types according to their therapeutic effect. For successful treatment, the following ten factors were to be kept in mind: 1) the organism (śarīra); 2) its maintenance (vṛtti); 3) cause of disease (hetu); 4) nature of disease (vyādhi); 5) action or treatment (karma); 6) effects or results (kārya); 7) time (kāla); 8) agent or the physician (kartā); 9) the means and instruments (karaṇa); and 10) the decision on the line of treatment (vidhi viniścaya).

Suśruta considers the head as the centre of the senses and describes cranial nerves associated with specific sensory function. Based on the derangement of the doṣas, he classifies a total of 1120 diseases. Caraka, on the other hand, considers the diseases to be innumerable. The doṣa-type diseases are called *nija*, whereas those with an external basis are called *āgantuka*. The

microbial origin of disease and the infective nature of diseases such as fevers, leprosy, smallpox, and tuberculosis was known. According to Suśruta, all forms of leprosy, some other skin conditions, tuberculosis, opthalmic and epidemic diseases are born by air and water and may be transmitted from one person to another. These diseases are not only due to the derangement of vāyu, pitta, and kapha, but also of parasitic origin. He adds: “There are fine organisms that circulate in the blood and are invisible to the naked eye which give rise to many diseases.” Parasites were classified into five types: sahaḥja (symbiotic parasites), parīṣaḥja (derived from faeces), kaphaḥja (derived from mucus), śoṇitaḥja (derived from the blood stream), and malaḥja (derived from the waste products of the body).

Another classification, based on etiological factors, divided disease into seven categories: 1) hereditary conditions based on the diseased germ cells (ādibala); 2) congenital disease (janmabala); 3) diseases due to the disturbance of the humours (doṣabala); 4) injuries and traumas (sanghātabala); 5) seasonal diseases (kālabala); 6) random diseases (daivabala); and 7) natural conditions such as aging (svabhāvabala).

The diseases of the head and the nervous system were given in detail. Amongst the nervous disorders described are convulsions, apoplectic fits, hysteric fits, tetanus, dorsal bending, hemiplegia, total paralysis, facial paralysis, lockjaw, stiff neck, paralysis of the tongue, sciatica, St. Vitus’ dance, paralysis agitans, and fainting. Four kinds of epilepsy was described. It was instructed that once the attack is over, the patient should not be rebuked and he should be cheered with friendly talk.

Suśruta devoted one complete chapter to interpretation of dreams, believing that dreams of the patient, together with other omens can be an indication to the outcome of the treatment.

Āyurveda was also applied to animal welfare. Texts on veterinary science describe the application of the science to different animals. Refuges and homes for sick and aged animals and birds were endowed. An āyurveda for plants and trees was also practised.

To summarize, Indian science was multifaceted, with abstract theories on the one hand and strict protocols for experiments on the other, as in medicine. Mathematics was used not only in astronomy and music but also in humanistic subjects such as language.

3 Cosmology of Greek science

The Greek tradition, like the Indian, is pluralistic. Amongst the cosmologies described are: (i) a structure ordered by a supreme principle (Plato); (ii) cosmos as a balance of equal but opposed forces (e.g. Anaximander, Parmenides, and Empedocles); (iii) a cosmos where war and strife are universal (Homer).

The idea that the universe is a machine under the guidance of a rational intelligence became prominent at a point. Plato and Aristotle supported this view, though with different emphasis. For Plato the Craftsman is transcendent, whereas for Aristotle it is an immanent force and nature itself is purposeful. Later philosophers denied the idea that the universe is a product of design. The atomists and the Epicureans believed that the world was a product not of design, but necessity out of the mechanical interactions of atoms.

There were multiple views about the creation of the universe. Plato (427-347 BC) appeared to support the view that the universe is one and created; for Aristotle, it was one and eternal; for Empedocles, it goes through cycles of creation and destruction. But these speculations were not associated with specific numbers as in the great cycles of Indian cosmology.

The early Greeks came into contact with older civilizations and learned their mathematics and cosmologies. Thales of Miletus (born about 624 BC), listed later as the first philosopher, went to Egypt where he learned geometry which he introduced to Greece. He believed that the earth floats on water. His student Anaximander believed the earth to be surrounded by a series of spheres made of mist and surrounded by a big fire. In a different version of his cosmology he imagined the earth to be a cylinder floating in space.

Empedocles believed the cosmos to be egg-shaped and governed by alternating reigns of love and hate. He took all matter to be composed of four elements: earth, water, fire, air. These four elements arise from the working of the two properties of hotness (and its contrary coldness) and dryness (and its contrary wetness) upon an original unqualified or primitive matter. The possible combinations of these two properties of primitive matter give rise to the four elements or elemental forms. In another theory, Anaximines claimed that everything was made of air. Earth was some sort of condensation of air, while fire was some sort of emission from air. When earth condenses out of air, fire is created in the process.

Pythagoras (560-480 BC) was born on the isle of Samos off the coast of Asia Minor. He travelled widely and studied with priests and healers in several foreign lands, collecting their writings and manuscripts. Between the age of 30 and 40 he he went into exile from Samos because he did not want to live under the rule of Polycrates, the tyrant. He settled down in the Greek colony in southern Italy called Croton, where he finally established the Pythagorean School. The Pythagoreans believed in reincarnation and they were vegetarians.

The Pythagoreans symbolized the elements as geometric forms as part of the belief that numbers were the language of physics and psychology. The ether element (the sphere of the whole) is represented by neutrality, spaciousness, and invisibility and its qualities were symbolized by the twelve faced dodecahedron. The air element is cold, light, quick and it is symbolized by a small blue eight faced octahedron. The symbol of the fire element is a very small hot, red, active, four faced tetrahedron, and that of water is a larger, moist, white 20 faced, white icosahedron. The earth is symbolized by a large, dry, yellow, six faced hexahedron. The fire is the smallest and most active, the air is slightly larger than fire and very light, the water is slightly larger and heavier, and the earth is the largest and most dense. Later, in the *Timaeus*, Plato proposed that the geometric solids constituted the elemental shapes of the physical atoms of matter and he based his theory of physics on the qualities of their sizes and shapes.

The Greek naturalists called the dynamic vital force the fiery pneuma, which is the primordial energy that pervades all phenomena. The expansions and contractions of this pneuma produces a space that includes hot and cold areas, as well as light and heavy areas of concentration. These universal elements manifest as the five archetypal elements ether, air, fire, water, earth. The constant ebb and flow of these primordial five elements created the interchange of mass and energy which manifested the galaxies, solar systems and planets. The flux of these elements produces the phenomena of nature we observe as the day and night, the waxing and waning of the moon, the passing of the four seasons and the processes of biological life itself.

But ordinary matter was constituted of only four elements, the fifth represented the heavens.

Medicine

The Pythagoreans believed that just as the universe has its central fire, the human body has its essence in heat; the heat of the seed and of the uterus are the origin of all life; the body attracts to itself the external air on account of its desire that heat should be tempered by cold and thus resolves itself in respiration.

Empedocles, who proposed the four-element theory, was the founder of the Italian school of medicine. He also noted that the blood and the respiration of air were linked and noted that the pores of the skin also breathed. Parmenides (450 BC) also wrote works on physiology and psychology. He believed that the mental and emotional state of a person was determined by the proportion of heat and cold in the human body.

The exchange of the cooling external air and the fiery internal heat is the cause of both respiration and circulation which stimulates the absorption and elimination of liquid and solid nourishment. The synergistic combination of the five elements and the pneumatic vital force produces the four humoral constituents from air, food and water. These four humours are the cold and dry bile, the hot and moist blood, the moist and cold phlegm, and the dry and hot choler.

In Greek medicine, any excess or deficiency of the four elements and four humours, disruptions of the three energies, wind (breath), heat (bile) and cold (phlegm) produce the state of disease. These factors show that the Pythagorean's theory of medicine has much in common with the Āyurveda which uses the five elements, together with the tridhātu (the three forces) and tridoṣa (the three faults).

The most famous person in Greek medicine is Hippocrates, a contemporary of Plato, known now for the oath that the doctors had to take. Many texts attributed to Hippocrates shed light upon the Hippocratic method of medicine. None of these texts may be identified as Hippocrates' own work, however. These works are called the Corpus Hippocraticum and number upwards of sixty. Galen, practicing medicine at Rome in the latter half of the Second Century AD, was certain, that Hippocrates himself wrote Epidemics I and III. Scholars have suggested that the texts may have been part of a library collection, originally from Cos, that was subsequently moved to Alexandria and then added upon, building the collection of medical texts we have today. While not primary sources, these works were written by

Hippocrates' students and practitioners of his medical theory.

The Hippocratic physician's first option was to suggest a regimen to his patient. This treatment consisted of advice regarding what the patient should eat and drink, and the amount of sleep and exercise he needed; it amounted to a cautious "let nature take its course" approach. The purpose of the regimen was to void the body of the imbalanced humour through a diet and exercise program. The physician would tailor such a regimen to the time of the year and to specific patient characteristics, and would wait until his patient's condition noticeably improved or worsened. The Hippocratic text *Aphorisms* outlined the order that the treatments were to follow: "What drugs will not cure, the knife will; what the knife will not cure, the cautery will; what the cautery will not cure must be considered incurable."

The choice of drugs to be administered was predicated upon the perceived humoral imbalance the physician sought to correct. The drug of choice was hellebore, popular because it induced both vomiting and diarrhea, tangible side effects the physician would interpret as the voiding of the humor. Hellebore, an extremely poisonous plant sometimes killed the patient; those lucky enough to quickly void themselves of its poison managed to survive. The physician could justify such drastic treatment because he believed that the purged material indicated he had successfully balanced the offending humor and thus treated his patient.

Not surprisingly, this treatment also left the patient in worse health, so the physician adopted even more aggressive methods to cure him. The physician resorted to the knife and blood-letting as a solution to the illness. Venesection was practiced ostensibly because it allowed the imbalanced humor a means of directly escaping the body, thereby restoring the humoral balance and the person's health. The physician would cut furthest away from the point that hurt, drawing the humours away from that painful spot. He would choose the amount of blood he wanted to spurt out by placing a cup over the bleeding incision; once the cup had filled, the physician was satisfied that he had completed treatment.

The physician's last-ditch effort was cauterization. Assuming that the patient had not yet died from either the disease or the previous treatments, cauterization involved burning the skin in one last attempt to "consume" the excess humor. Then the physician would allow the resulting wound to ulcerate, which he would then irritate with caustic drugs, like mustard-seed paste, to allow the humours to slowly drain out of the body. The area chosen

for cauterization was to be located as far as possible from the actual wound, again to draw the excess humours from the painful spot.

In common with other intellectuals in the Greek city-states, Hippocratics were interested in far-away places and peoples, in epidemic diseases and plagues, in the origins of man and embryology, and in dietetics. Hippocratics were quick to criticize causes and remedies that they considered irrational. The writer of “Diseases of Young Girls” censures women who follow commands from Artemis’ priests to dedicate costly garments to the goddess in the effort to cure madness in the premenarchic young girl. The author of “Sacred Disease” criticizes “witch-doctors, faith-healers, quacks and charlatans,” whose etiology for epilepsy and sudden seizures invokes attacks from the gods and whose therapies consist of purifications, incantations, prohibition of baths, lying on goat-skins and eating goats’ flesh (*Sacred Disease* 1-2).

The etiology for the disease in such examples is taken to be the blockage of inner vessels by a bodily humour. Treatment was to require the evacuation of the noxious fluid from vital areas of the body: the epileptic is to take a medicine to move excess phlegm gradually from his head so that its sudden descent into his body doesn’t overwhelm his senses, and the young girl is to sleep with a man as soon as possible to remove the impediment at the mouth of her uterus, while pregnancy will bring her long-lasting cure by opening up her body so that her excess fluids can move about freely.

Although one may criticize these methods, there was a basis of process that was invoked to explain a disease. This then qualified the system as being scientific. The Hippocratic system was to remain extremely influential in the West until the advent of modern medicine.

Elements and the solar system

We have already mentioned Plato’s mathematical construction of the elements (earth, fire, air, and water), in which the cube, tetrahedron, octahedron, and icosahedron are given as the shapes of the atoms of earth, fire, air, and water. The fifth Platonic solid, the dodecahedron, is Plato’s model for the whole universe.

Plato’s beliefs as regards the universe were that the stars, planets, the sun and the moon move round the earth in crystalline spheres. The sphere of the moon was closest to the earth, then the sphere of the sun, then Mercury,

Venus, Mars, Jupiter, Saturn and furthest away was the sphere of the stars. He believed that the moon shines by reflected sunlight.

Elements had a natural tendency to separate in space; fire moved outwards, away from the earth, and earth moved inwards, with air and water being intermediate. Thus, each of these elements occupied a unique place in the heavens (earth elements were heavy and, therefore, low; fire elements were light and located up high).

There were only seven objects visible to the ancients, the sun and the moon, plus the five planets, Mercury, Venus, Mars, Jupiter and Saturn. It was obvious that the planets were not on the celestial sphere since the moon clearly passes in front of the sun and planets, plus Mercury and Venus can be seen to transit the sun.

Slightly later, Aristarchus (270 B.C.) proposed an alternative model of the Solar System placing the sun at the center with the earth and the planets in circular orbit around it. The moon orbits around the earth. This model became known as the heliocentric theory. Aristarchus' model was ruled out by the philosophers at the time for the reason that there was no feeling on earth of its motion. It is interesting that although Aristarchus was the most prominent astronomer of his time, he assumed a figure of two degrees for the angular diameter of the moon, when the correct value is about one-half of a degree. Since the correct size is very easily ascertained, the criticism has been made that the Greeks did not have a tradition of observational astronomy.

Ptolemaic system

Ptolemy (200 A.D.) was the author of the *Almagest*, a treatise on the celestial sphere and the motion of the planets. The book is divided into 13 books, each of which deals with certain astronomical concepts pertaining to stars and to objects in the solar system. It was, no doubt, the encyclopedic nature of the work that made the *Almagest* so useful to later astronomers and that gave the views contained in it so profound an influence. In essence, it is a synthesis of the results obtained by Greek astronomy; it is also the major source of knowledge about the work of Hipparchus.

In the first book of the *Almagest*, Ptolemy describes his geocentric system and gives various arguments to prove that, in its position at the center of the universe, the earth must be immovable. Not least, he showed that if the earth moved, as some earlier philosophers had suggested, then certain phenomena

should in consequence be observed. In particular, Ptolemy argued that since all bodies fall to the center of the universe, the earth must be fixed there at the center, otherwise falling objects would not be seen to drop toward the center of the earth. Again, if the earth rotated once every 24 hours, a body thrown vertically upward should not fall back to the same place, as it was seen to do. Ptolemy was able to demonstrate, however, that no contrary observations had ever been obtained.

Ptolemy accepted the following order for celestial objects in the solar system: earth (center), Moon, Mercury, Venus, Sun, Mars, Jupiter, and Saturn. In particular, the sun appears to describe a yearly circular path called the ecliptic over the background of stars. However, when the detailed observations of the planets in the skies is examined, the planets undergo motion which is impossible to explain in the geocentric model, a backward track for the outer planets. This behavior is called retrograde motion.

He realized, as had Hipparchus, that the inequalities in the motions of these heavenly bodies necessitated either a system of deferents and epicycles or one of movable eccentrics (both systems devised by Apollonius of Perga, the Greek geometer of the 3rd century BC) in order to account for their movements in terms of uniform circular motion. In the Ptolemaic system, deferents were large circles centered on the earth, and epicycles were small circles whose centers moved around the circumferences of the deferents. The sun, moon, and planets moved around the circumference of their own epicycles. In the movable eccentric, there was one circle; this was centered on a point displaced from the earth, with the planet moving around the circumference. These were mathematically equivalent schemes.

Even with these, all observed planetary phenomena still could not be fully taken into account. Ptolemy now supposed that the earth was located a short distance from the center of the deferent for each planet and that the center of the planet's deferent and the epicycle described uniform circular motion around what he called the equant, which was an imaginary point that he placed on the diameter of the deferent but at a position opposite to that of the earth from the center of the deferent (i.e., the center of the deferent was between the earth and the equant). He further supposed that the distance from the earth to the center of the deferent was equal to the distance from the center of the deferent to the equant. With this hypothesis, Ptolemy could better account for many observed planetary phenomena.

Crystalline spheres

Although Ptolemy realized that the planets were much closer to the earth than the “fixed” stars, he believed in the physical existence of Plato’s crystalline spheres, to which the heavenly bodies were said to be attached. Outside the sphere of the fixed stars, Ptolemy proposed other spheres, ending with the *primum mobile* (“prime mover”), which provided the motive power for the remaining spheres that constituted his conception of the universe.

This model, while complicated, was a complete description of the Solar System that explained, and predicted, the apparent motions of all the planets. This, however was not universally accepted. The most notable detractor was Democritus who postulated the existence of indestructible atoms (from the Greek *a-tome*: that which cannot be cut) of an infinite variety of shapes and sizes. He imagined an infinite universe containing an infinite number of such atoms, in between the atoms there is an absolute void.

Aristotle’s cosmology

Aristotle’s cosmological work *On The Heavens* presents the mainstream view of Greek cosmology. Aristotle believed in just four elements: earth, water, air and fire. These elements naturally move up or down, fire being the lightest and earth the heaviest. A composite object will have the features of the element which dominates.

The idea that all bodies, by their very nature, have a natural way of moving is central to Aristotelian cosmology. Movement is not, he states, the result of the influence of one body on another. Some bodies naturally move in straight lines, others naturally stay put. But there is yet another natural movement: the circular motion. Since to each motion there must correspond a substance, there ought to be some things that naturally move in circles. Aristotle then states that such things are the heavenly bodies which are made of a more exalted and perfect substance than all earthly objects.

Since the stars and planets are made of this exalted substance and then move in circles, it is also natural, according to Aristotle, for these objects to be spheres. The cosmos is then made of a central earth (which he accepted as spherical) surrounded by the moon, sun and stars all moving in circles around it. This conglomerate he called “the world”. Although celestial bodies are perfect, they must circle the imperfect earth. The initial motion

of these spheres was caused by the action of a “prime mover” which acts on the outermost sphere of the fixed stars; the motion then trickles down to the other spheres through a dragging force.

Aristotle also addresses the question whether this world is unique or not; he argues that it is unique. The argument goes as follows: earth (the substance) moves naturally to the center, if the world is not unique there ought to be at least two centers, but then, how can earth know to which of the two centers to go? But since “earthy” objects have no trouble deciding how to move, he concludes that there can only be one center (the earth) circled endlessly by all heavenly bodies.

It is interesting to note that Aristotle asserts that the world did not come into being at one point, but that it has existed, unchanged, for all eternity (it had to be that way since it was “perfect”); the universe is in a kind of “steady state scenario”. Still, since he believed that the sphere was the most perfect of the geometrical shapes, the universe did have a center (the earth) and its “material” part had an edge, which was “gradual” starting in the lunar and ending in the fixed star sphere. Beyond the sphere of the stars the universe continued into the spiritual realm where material things cannot be.

On the specific description of the heavens, Aristotle created a complex system containing 55 spheres. One of the fundamental propositions of Aristotelian philosophy is that there is no effect without a cause. Applied to moving bodies, this proposition dictates that there is no motion without a force. Speed, then is proportional to force and inversely proportional to resistance.

Qualitatively this implies that a body will traverse a thinner medium in a shorter time than a thicker medium (of the same length): things will go faster through air than through water. A natural (though erroneous) conclusion is that there could be no vacuum in Nature, for if the resistance became vanishingly small, a tiny force would produce a very large “motion”; in the limit where there is no resistance any force on any body would produce an infinite speed. This conclusion put him in direct contradiction with the ideas of the atomists such as Democritus. Aristotle concluded the atomists were wrong, stating that matter is in fact continuous and infinitely divisible.

For falling bodies, the force is the weight pulling down a body and the resistance is that of the medium (air, water, etc.). Aristotle noted that a falling object gains speed, which he then attributed to a gain in weight. If weight determines the speed of fall, then when two different weights are

dropped from a high place the heavier will fall faster and the lighter slower, in proportion to the two weights. A ten pound weight would reach the earth by the time a one-pound weight had fallen one-tenth as far.

Zeno's paradoxes

An excellent example of the Greek application of logic in understanding motion is captured by the paradoxes of Zeno (fifth century BC). These paradoxes, which are variations on a single theme, emerge because of the consideration of space and time as discrete.

1. *Dichotomy paradox*: Before a moving object can travel a certain distance, it must travel half that distance. Before it can travel half the distance it must travel one-fourth the distance, and so on. This sequence goes on forever, therefore, the original distance cannot be traveled, and motion is impossible.
2. *Achilles and the tortoise paradox*: Achilles gives the tortoise a head start in a race. Before he can overtake the tortoise, he must run to the place where the tortoise began but the tortoise has moved on to some other point. From there, before he can overtake the tortoise, he must run to the place where the tortoise had moved to. This goes on forever, and Achilles can never pass the tortoise.
3. *Arrow paradox*: If you look at an arrow in flight, at an instant in time, it appears the same as a motionless arrow. Then how does it move?

Archimedes and physics

Archimedes (3rd century BC) contributed many new results to mathematics, including successfully computing areas and volumes of two and three dimensional figures and a geometrical argument for an approximation of π . His major contributions to physics are his principle of buoyancy, and his analysis of the lever. He also invented many ingenious technological devices, many for war, but also the Archimedean screw, a pumping device for irrigation systems.

According to the Roman historian Vitruvius, Hiero, after gaining the royal power in Syracuse, resolved, as a consequence of his successful exploits,

to place in a certain temple a golden crown which he had vowed to the immortal gods. He contracted for its making at a fixed price and weighed out a precise amount of gold to the contractor. At the appointed time the latter delivered to the king's satisfaction an exquisitely finished piece of handiwork, and it appeared that in weight the crown corresponded precisely to what the gold had weighed. But afterwards a charge was made that gold had been abstracted and an equivalent weight of silver had been added in the manufacture of the crown. Hiero asked his friend Archimedes to investigate the matter. While in a tub for his bath, Archimedes discovered the principle of buoyancy (hydrostatics or the Archimedes Law), according to which the water displaced equals the mass of the body. Without a moments delay and transported with joy, he jumped out of the tub and rushed home naked, crying in a loud voice "Eureka, Eureka."

Archimedes' Principle states that the buoyancy support force is exactly equal to the weight of the water displaced by the immersed object, that is, it is equal to the weight of a volume of water equal to the volume of the object.

Although leverage has been used to move heavy objects since prehistoric times, it appears that Archimedes was the first person to appreciate just how much weight could be shifted by one person using appropriate leverage. It is believed that he also invented a screw for pumping water upwards.

4 Comparing Indian and Greek sciences

We first note that when we speak of a formal science, more than a list of general ideas it is the elaboration of a system. Using this definition, medicine is the best examples of a full-fledged science from the ancient world. The Greek and Indian medical sciences have some points of commonality, but they also have distinct differences. The Greek system emphasizes the mechanical aspects of humours, whereas the Indian system considers connections with the mind as well. The Indian system has many recursive levels, it has a psychosomatic concept of disease, and it is a more comprehensive medical system. My personal judgment is that Āyurveda is superior to the Hippocratic system which is why it is still practiced in India and the West.

In other fields, the level of knowledge varied. Considering the work of Archimedes, it is clear that Greek knowledge of hydrostatics was more advanced. On the other hand, Indian inner sciences (psychology) were more

sophisticated and the Indians had greater success in grammar and in the conception of the physical universe.

The differences between the two traditions arose from their respective cosmologies, which is why they did not attempt to learn from each other. The Indian cosmos was infinite with a postulated connection between the inner and the outer. The Greek cosmos was a finite system.

Greek priority

This view flies against great mass of evidence. For example, the references to the three humours in the Atharvaveda are prior to Plato by any reckoning. Likewise, the Baudhāyana Śulbasūtra is prior to Greek geometry. Indian astronomy is also earlier as evidenced by its description in the Śatapatha Brāhmaṇa and the Vedāṅga Jyotiṣa.

For some time the Śulbasūtras themselves were considered to be very late, after Euclid, in spite of the powerful linguistic arguments against this view. But when it was discovered the same geometry was present in the Śatapatha Brāhmaṇa, which is dated prior to 600 BC in the most conservative chronologies, the circular logic of such chronology became evident.²⁰ Similar misguided logic was used to assign the date of 500 BC to the Vedāṅga Jyotiṣa, which has an inner date of roughly 1300 BC, to make its astronomy dependent on Greek and Babylonian sources.

Common prior origin

This theory comes in two main forms. In the first one, which is a variant of the standard Eurocentric view, it is conceded that the Greek culture was indebted to the Mesopotamians and the Egyptians, and these taken together form the basis of Western science.

The second version includes Indian evidence. The Śulbasūtra geometry is different from the Mesopotamian one in that it is constructive and not purely algebraic and it shares features with Greek geometry. Therefore, if there is common origin that must be in the shared Indo-European heritage. In other words, this geometric knowledge must have been a part of the itinerant Indo-European tribes as they moved through Central Asia, ending up later as the Vedic Indians and the Greeks.²¹

But the Greek tradition doesn't know archaic aspects of Vedic science

which are more central to the knowledge system than geometrical knowledge. Therefore the idea of common prior origin must be discounted.

Indian priority

There are elements of the Greek system which were clearly borrowed from outside. Thales and Pythagoras travelled out of the country and introduced new ideas. The Pythagorean ideas on five elements, vegetarianism and reincarnation appear to have an Indian origin. The Pythagoras theorem of geometry may have had an Indian origin since it is described in the Śulba Sūtras. However, such broad concepts do not make a system. It is the amplification of these ideas which reflects the national genius.

The history of Greek science is well understood. It is clear that while it may have been inspired initially by foreign impulses, it adopted a unique trajectory and there is no evidence that it was in any way dependent on Indian science later. In astronomy, for example, there is no evidence of the use of Indian methods. Greek medicine is likewise different from Indian medicine in crucial details.

Independent development

The physics, philosophy, and medicine of the Greeks was undoubtedly a result of the characteristic elaboration within Greece. Even the idea of five elements did not become the mainstream view and the Hippocratics and Aristotle spoke only of four elements.

The Indian system of five elements is connected to the five-fold recursive division of reality in Sāṃkhya. On the other hand, the emergence of a fifth element in Greek thought was a gradual process. In the common conception of the universe shared by most religious and philosophical thinkers in the centuries before Plato, the cosmos, a sphere bounded by the sky, contains the conflicting "opposites" (the hot/the cold, the wet/the dry) which became (via Empedocles) the four root substances earth, water, air and fire.

The astronomies of India and Greece are quite different. The elaboration of logic is also distinctively different. In view of all of this, the developments of Greek and Indian science must be considered independent.²²

5 Zodiacal signs and Greek astronomy in India

The argument for a Greek origin of the later Indian astronomy was articulated most vehemently by W.D. Whitney in the closing decades of the 19th century. He suggested that the transmission of Greek ideas took place sometime before Ptolemy because the Indian methods do not mention the techniques introduced by him. He also suggested that this transmission must have occurred in consequence of the “lively commerce between Alexandria as the port and mart of Europe and the western coast of India [during the first centuries of our era].”²³ He was certain that India could not have been the place of the origin of Indian astronomy because he believed that Indian history did not go further back than 2000 BC.

Whitney’s theory hinges around the use of the words *liptā*, *horā*, and *kendra* for minute, hour, and the mean anomaly, which are supposed to be of Greek origin. Furthermore, he believed that there is scant mention of the planets in early texts, the names of the days after the planets, and the division of the circle into signs, degrees, minutes, and seconds is fashioned after Greek usage.

E. Burgess countered Whitney with arguments related to the lunar and solar divisions of the zodiac, the epicycle theories, astrology, and the names of the five planets.²⁴ I summarize below these arguments strengthened with the new insights that have been obtained by recent research.²⁵

1. *Lunar zodiac.* The demonstration that the Ṛgveda itself contains the list of the 27 nakṣatras in terms of their presiding deities²⁶ establishes that the lunar zodiac has a greater antiquity in India as compared to the Chinese and the Arabs. Furthermore, the beginnings of the Indian tradition are now believed to be several thousand years earlier than thought by Whitney.
2. *Solar zodiac.* I have recently shown²⁷ that the solar zodiac arose in India since the names and symbols of the signs are intimately related to the deities of the corresponding nakṣatras, whereas they appear out of context in Babylonia and Greece. Burgess anticipated this when he stated that this twelve-part “division was known to the Hindus centuries before any trace can be found in existence among any other people.”

3. *The theory of epicycles.* I concur with Burgess's judgment that "the difference of this theory in the Greek and Hindu systems of astronomy precludes the idea that one of these people derived more than a hint respecting it from the other. And so far as this point alone is concerned, we have as much reason to suppose the Greeks to have been the borrowers as the contrary; but other considerations seem to favor the supposition that the Hindus were the original inventors of this theory."
4. *Coincidence in the systems of astrology.* According to Burgess, "The coincidence that exist between the Hindu and Greek systems are too remarkable to admit of the supposition of an independent origin for them. But the honor of original invention, such as it is, lies, I think, between the Hindus and the Chaldeans. The evidence of priority of invention and culture seems, on the whole, to be in favor of the former; the existence of three or four Arabic and Greek terms in the Hindu system being accounted for on the supposition that they were introduced at a comparatively recent period. In reference to the word *horā* it may not be inappropriate to introduce the testimony of Herodotus: 'The sun-dial and the gnomon, with the division of the day into twelve parts, were received by the Greeks from the Babylonians.' There is abundant testimony to the fact that the division of the day into twenty-four hours existed in the East, if not actually in India, before it did in Greece. In reference to the so-called Greek words found in Hindu astronomical treatises, I would remark that we may with entire propriety refer them to the numerous class of words common to the Greek and Sanskrit languages, which either come to both from a common source, or passed from the Sanskrit to the Greek at a period of high antiquity; for no one maintains, so far as I am aware, that the Greek is the parent of Sanskrit."

An examination of the Vedic texts completely settles this question.²⁸ We have overwhelming evidence supporting the view that the twelve part division of the circle goes back to the Ṛgvedic period itself. The Indians derive the word *horā* from *ahorātra* (day-night) which is attested in the Vedic texts.

5. *Names of planets.* Burgess argued that the application of the names of the planets to the days of the week was unknown to the Greeks and

not adopted by the Romans until a late period. He concurred with H.H. Wilson, who said: “It is commonly ascribed to the Egyptians and Babylonians, but upon no very sufficient authority, and the Hindus appear to have at least as good a title to the invention as any other people.”

The planets are actually mentioned in the Vedic texts.²⁹

Burgess emphasized that the Arabs were thoroughly imbued with the knowledge of the Hindu astronomy before they became acquainted with that of the Greeks. This is established by the Arab translations of Ptolemy’s *Syntaxis* (*Almagest*). In the Latin translations of this book, the ascending node is called *nodus capitis*, “the node of the head,” and the descending node *nodus caudae*, “the node of the tail (ketu),” which are pure Hindu appellations.

Burgess concluded by speaking of the detailed methods: “In the amount of the annual precession of the equinoxes, the relative size of the sun and moon as compared with the earth, the greatest equation of the centre for the sun – the Hindus are more nearly correct than the Greeks, and in regard to the times of the revolutions of the planets they are very nearly correct in four times, and Ptolemy in six. There has evidently been very little astronomical borrowing between the Hindus and the Greeks. And in regard to points that prove a communication from one people to the other, I am inclined to think that the course of derivation was from east to west rather than from west to east.”

The opinions of Burgess are strengthened by our improved knowledge of the astronomy of the Vedāṅga Jyotiṣa and the discovery of the astronomy of the Vedic fire altars.³⁰ Neither should we forget that the cosmological basis of the Indian sciences was much more subtle and comprehensive than that of Greek science. The achievements of Indian sciences in the fields of mathematics, grammar, and the comprehensiveness of its medical science also show that the Indian sciences were more advanced than the corresponding Greek sciences during the glory days of Greek civilization.

The thesis that Indian siddhāntas were based on Greek and Babylonian measurements has been fully refuted by Billard and van der Waerden and so it will not be discussed here.³¹ It is noteworthy that the framework of the siddhāntas was very different from that of Greek models. For example, Āryabhaṭa’s astronomy considers the earth to rotate on its axis and the

planets to go around the sun, which, in turn, is taken to go around the earth. This model was more advanced than contemporaneous models in the ancient world.³²

6 Conclusions

We have indirect evidence that there was a period of interaction between Indian and Greek science before the flowering of Greek philosophy. This was the time when the Greeks borrowed from many sources that apparently included the Indian. But the importance of this borrowing must not be exaggerated since it merely consisted of general ideas such as five elements of reality or the 360-part division of the circle.

The Greeks were fully aware of the Asiatic origin of their ideas. For example, Strabo informs us³³ that music “from the triple point of view of melody, rhythm and instruments” came to them originally from Thrace and Asia. Further, “the poets, who make the whole of Asia, including India, the land or sacred territory of Dionysos, claim that the origin of music is almost entirely Asiatic.” Study of music and mathematics go hand in hand, showing the Greek awareness of the Eastern connection with their own traditions.

Subsequent to that, Greek and Indian sciences appear to have developed independently although after the time of Alexander they were consciously aware of each other. The focus and style of the two sciences was different owing to their different cosmologies. Perhaps the only science which worked more or less the same way in the two civilizations was medicine. But even here there were important differences.

The reason why the two sciences went their own way in spite of the knowledge of the other was because their worldviews were different. Indian astronomers, for example, never paid any attention to Ptolemy’s model as its crystalline sphere basis looked very primitive compared to the vastness of their own conception. On the other hand, the use of enormous time scales of Indian astronomy must have appeared unnecessary to the Greeks.

There was no specific technology that arose at this early date that might have caused India or Greece to question its own system and become receptive to new ways of doing things. The power and influence of the Greek ideas arose out of the narrative and style of its philosophers and scientists. Its influence was primarily through its literature and philosophy. Likewise,

Indian influence all over Asia was through its philosophy, medicine, and the arts and its narrative texts. Science could take its next steps only after the development of new technology which opened up new worlds of the small and the large.

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