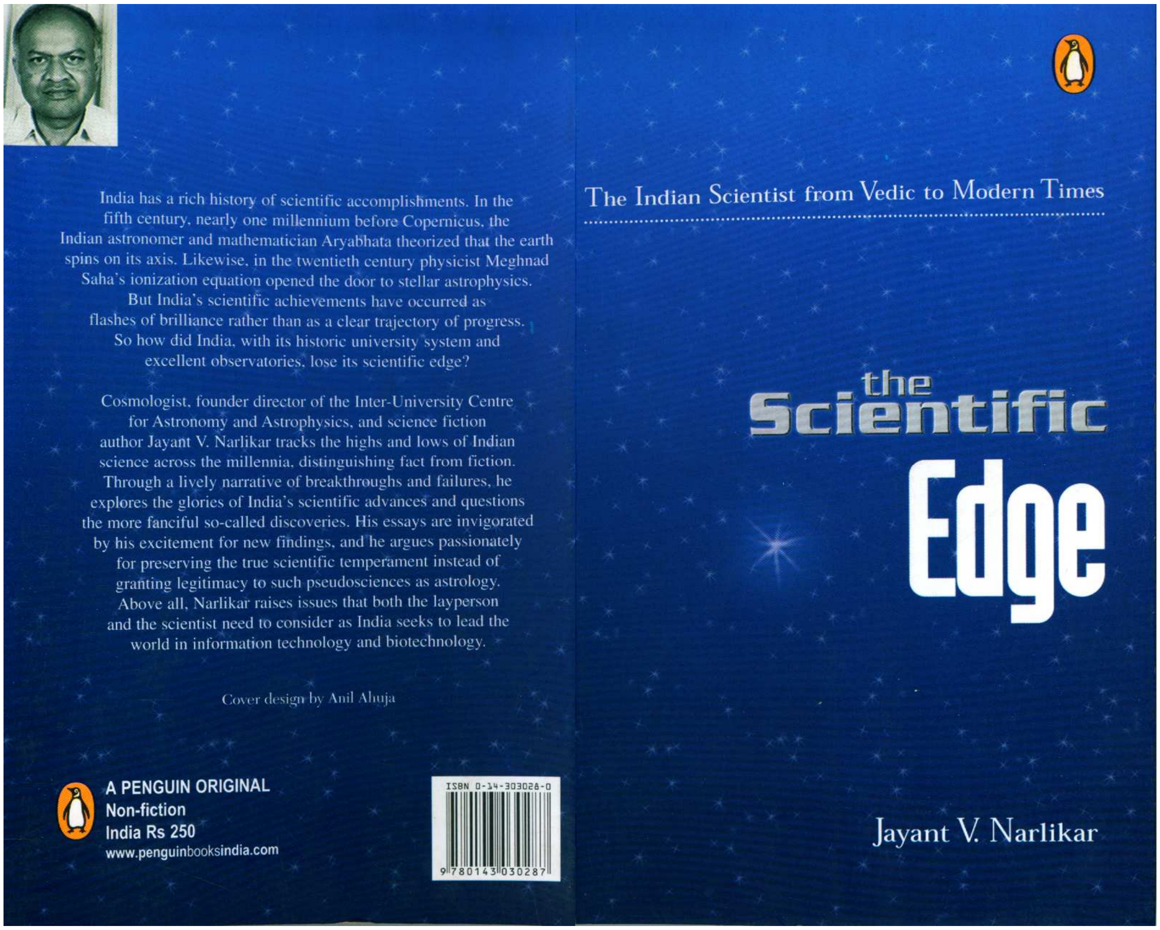

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THE SCIENTIFIC EDGE

Jayant V. Narlikar was born in Kolhapur in 1938 and received his early education at Banaras Hindu University. He went to Cambridge University for higher studies in 1957, receiving his Ph.D in 1960 and Sc.D in 1976. After spending several years at Cambridge as a fellow of King's College (1963-72) and as staff member of the Institute of Theoretical Astronomy (1966-72), he returned to India as a professor at the Tata Institute of Fundamental Research in Mumbai (1972-89). He was later invited to Pune to set up the Inter-University Centre for Astronomy and Astrophysics, of which he was the founder director from 1988 to 2003. A well-known cosmologist, Narlikar has received several awards and recognitions, including the Padma Vibhushan in 2004, as also the Padma Bhushan earlier. He has also contributed to public outreach of science, for which he has received UNESCO's Kalinga Award.

The Scientific Edge

The Indian Scientist from Vedic to Modern Times

JAYANT V. NARLIKAR

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PENGUIN BOOKS
Published by the Penguin Group
Penguin Books India Pvt Ltd, 11 Community Centre, Panchsheel Park, New Delhi 110 017, India
Penguin Group (USA) Inc., 375 Hudson Street, New York, New York 10014, USA
Penguin Group (Canada), 90 Eglinton Avenue East, Suite 700, Toronto, Ontario, M4P 2Y3, Canada (a division of Pearson Penguin Canada Inc.)
Penguin Books Ltd, 80 Strand, London WC2R 0RL, England
Penguin Ireland, 25 St Stephen's Green, Dublin 2, Ireland (a division of Penguin Books Ltd)
Penguin Group (Australia), 250 Camberwell Road, Camberwell, Victoria 3124, Australia (a division of Pearson Australia Group Pty Ltd)
Penguin Group (NZ), cnr Airborne and Rosedale Roads, Albany, Auckland 1310, New Zealand (a division of Pearson New Zealand Ltd)
Penguin Group (South Africa) (Pty) Ltd, 24 Sturdee Avenue, Rosebank, Johannesburg 2196, South Africa

Penguin Books Ltd, Registered Offices: 80 Strand, London WC2R 0RL, England

First published by Penguin Books India 2003

10 9 8 7 6 5 4 3

Typeset in *Goudy Old Style* by SŪRYA, New Delhi
Printed at Pauls Press, New Delhi

Contents

THE SCIENTIFIC EDGE

The Indian Scientist from Vedic to Modern Times

Jayant V. Narlikar

India has a rich history of scientific accomplishments. In the fifth century, nearly one millennium before Copernicus, the Indian astronomer and mathematician Aryabhata theorized that the earth spins on its axis. Likewise, in the twentieth century physicist Meghnad Saha's ionization equation opened the door to stellar astrophysics. But India's scientific achievements have occurred as flashes of brilliance rather than as a clear trajectory of progress. So how did India, with its historic university system and excellent observatories^ lose its scientific edge?

Cosmologist, founder director of the Inter-University Centre for Astronomy and Astrophysics, and science fiction author Jayant V. Narlikar tracks the highs and lows of Indian science across the millennia distinguishing fact from fiction. Through a lively narrative of breakthroughs and failures, he explores the glories of India's scientific advances and questions the more fanciful so-called discoveries. His essays are invigorated by his excitement for new findings, and he argues passionately for preserving the true scientific temperament instead of granting legitimacy to such pseudoscience's as astrology. Above all, Narlikar raises issues that both the layperson and the scientist need to consider as India seeks lo lead the world in information technology and biotechnology.

Preface

When as a young lad of twenty-two I enrolled myself as a research student in science, my aim was to restrict my attention and career to research in astronomy- More than four decades later, I see that aim as confining myself to the proverbial ivory tower.

Indeed it was fortunate that my research supervisor was Fred Hoyle, a man hailed as the most original astronomer of the twentieth century and a distinguished popularizer of science and writer of science fiction. A close association with him gradually introduced me to the wider vista of the interaction of science and society as well as the subject of the historical evolution of science. Hoyle's example showed me that it. is possible to maintain a satisfactory level of research productivity while enlarging one's interests in these wider issues. In fact, these interests provided a more mature background to my research.

So it was that while in the UK and later after having returned to India I continued and expanded these interests through writing and lecturing. I discovered that the evolution of science in the subcontinent has followed a different track from that in the West. While interacting with the public, one runs into two different viewpoints. On the one hand, there is awareness that for various reasons India mounted the bus of science and technology rather late and has to make up for this. On the other hand, there is the feeling that in our ancient past we led the world in knowledge. More often than not these views are stated with undue vigour.

This book has evolved out of my interest in the area spanned by these two extremes of views. The chapters here have followed a broad historical sequence, although not strictly so. Starting from our Vedic heritage, through the Siddhantic and post-Siddhantic periods, then the colonial era and through post-Independence to the present times to some futuristic ideas, this book is a ramble through the pathway of Indian science across the millennia from the perspective of an Indian cosmologist.

This pathway takes us beyond science per se to issues of social mindset, higher education in general, the scientific temper, the apparent confrontation between science and religion, and the dissemination of science to the public at large. The final chapter asks whether this entire cultural-educational-scientific enterprise has any overlap with the religious-philosophical quest of mankind.

Because of my long association with astronomy, there is inevitably an astronomical bias when reviewing the progress of science. However, astronomy historically formed a major part of science. Indeed, one can say that it was only in the post-Newtonian era that laboratory science began to assert its primacy over astronomy.

At the outset, I should issue a disclaimer that I do not profess to be an expert in any of the areas upon which I have ventured to write, but I have enjoyed sharing my interest—and, at times, ignorance—with the reader. Many scholars far more experienced and distinguished than I have written on some of these themes, but there have been very few from India. This book may help remedy that in a small way.

I would like to record my grateful thanks to Rajesh Kochhar for his permission to include some historical portions from our joint book, Astronomy in India: *Past, Present and* Future, and to Saroja Bhate for her permission for reproducing parts of our joint report on the project on the search for old Indian records of the sighting of the Crab supernova explosion in A.D. 1054.

Finally, my thanks to Krishan Chopra of Penguin for encouraging me to write on these topics and to Heidi Vierow for making numerous suggestions that have (I think) improved the presentation.

Pune

July 2003

PART I

India's Science in a Historical Context

This book begins with a review of India's manifold contributions to science in the ancient past, first highlighting those contributions of which we can be proud and then indicating others which are much hyped but either vaguely worded or simply trivial. It then recalls the old centres of learning like Takshashila and Nalanda, which systematized higher education very similar to today's residential universities.

Chapter 4 looks back to see why this momentum petered out and India got left out of the revolution in science and technology that started in Europe four centuries ago. Amongst many causes may be mentioned the stress on oral education with the consequent lack of written works. It was the paucity of ancient manuscripts that one finds responsible for lack of reliable records of astronomical events like star explosions (supernovae).

Chapter 6 describes the slow renaissance of science in India through collaborations with the European colonizers like the Portuguese, the French and of course the British. However, we discuss in the last chapter the parallel need for social reform that would make the 'alien' scientific ideas acceptable to the native society. Here the work of reformers like Raja Rammohun Roy stand out.

Things to Be Proud of . . .

Whenever there is a discussion of Indian science, a topic that is invariably brought up, especially by laypersons, is the enormous strides made by our ancestors in the good old days, now alas long past. When pressed for details, the claim is backed up by citing ancient epics like the *Ramayana,* the *Mahabharata* or any of the innumerable Puranas that contain episodes whose imaginativeness would put even modern science fiction to shame—black holes, guided missiles and weapons of universal destruction, sighting of events occurring far away, destruction by laser-like rays, time dilatation, and medicines that snatch life back from the jaws of death. If myths from that period contain such details, so the argument goes, surely the reality must have had some ambience of high technology, and high technology could not have been possible without sophisticated science. Ergo, our ancient ancestors must have been scientifically advanced.

Let us not get carried away by myths, howsoever exciting and absorbing they may be. Ancient Greece also had epics like the *Iliad* and the *Odyssey,* but it also has evidence in the writings of Euclid, Pythagoras and Archimedes, work which is scientifically much more interesting but otherwise much more mundane than the adventures of Theseus, Achilles or Ulysses.

Euclid's *Elements* describe the subject of geometry as an intellectual exercise built upon axioms and important theorems derived from them through logical reasoning. Pythagoras' theorem— the theorem that the square on the hypotenuse of a right-angled triangle equals in area the sum of the squares on its two sides-is one such feat. Whereas Euclid's results satisfy our innate aspiration for reason and logic, the work of Archimedes confronts us with the practical aspects of life by discovering for us some of nature's secrets and showing us how to put them to use to improve our lot. Let us look for similar positive aspects of ancient Indian contributions to the pure and applied aspects of science, as established from well-documented evidence.

The *Shulva Sutra*

No description of ancient Indian mathematics can be complete without reference to the *Shulva Sutra,* which belongs to the literature of Vedic times (c.1500-c. 200 B.C.). The name itself means rules of measurement. It is interesting that since lengths were measured by ropes, the word *shulva* later came to be known as *rope.* The origins of the Sutras can be traced to the Vedas, and they may have been known at least eight to nine centuries B.C.

The ideas presented in this collection seem to have been motivated by the practical considerations of sacrificial rituals. The yajnas (sacrifices) were performed in Aryan/Vedic times to propitiate the divine powers or more generally as parts of religious rites. The size of the platform for yajnas and other related issues provoked questions of measurement and hence of geometry. The *Shulva Sutra* contains, for example, Pythagoras' theorem but not the proof of the theorem, as Euclid's Elements does. Nevertheless, as a correct result, the statement should be renamed as the Shulva theorem.

Likewise, consider the problem known as squaring the circle-using a ruler and a compass to find the size of the square whose area equals that of a given circle. As late as the nineteenth century it was unsolvable. The area of a circle of unit radius is Л*,* and so one needs to construct a square of area Л. How much is Л? If we write Л as a decimal number 3.14159 . . ., it will be a non-terminating number and, while we can extend the above sequence of numbers as far as we want, no simple general rule tells us what the number in any specified decimal position should be. Such a number is called an irrational number. Modern mathematics, however, provides formulae for working out the value of Л as accurately as we want.

Good approximations of irrational numbers like Л and root 2 were known to ancient Indian mathematicians. Again, we find these expressions given without proof. For example, the *Shulva Sutra* gives the following approximation for root2 but without explicit proof:

1 + 1/3 + 1/ (3 x 4) - 1/ (3 x 4 x 34)

The *Baudhayana* and the *Apastambha Sutras* belonging to the Krishna *Yajurveda* describe indeterminate equations of the first degree, more commonly known as Diophantine equations because of their Greek origin. The Greek discovery, however, came much later, and it is more appropriate to recognize their origin as coming from the *Shulva Sutra.*

The discovery acknowledged and ascribed to the Vedic era most commonly today is that of the zero and the decimal system of writing numbers. Books like the *Yajurveda Samhita, Taittiriya Samhita, Vajasaneyi Samhita* give large numbers in the decimal system as powers of ten, with the largest explicitly mentioned being 10^{19}. Although numbers like 27 are described as *sapta-vimshati* (twenty-seven), thus clearly ascribing place values to the ordered numerals in a number, there is also the method of expressing a number close to a power of ten by subtraction; for example, 972 is described as twenty-eight less than a thousand.

In this connection it is worth citing a speech made by the Nobel laureate physicist Abdus Salam that explains how the Indian discovery may have spread to Asia and Europe, albeit much later:

Almost exactly twelve hundred years ago, Abdullah Al Mansur, the second Abbasid Caliph celebrated the founding of his new capital, Baghdad, by inaugurating an international scientific conference. To this conference were invited Greek, Nestorian, Byzantine, Jewish as well as Hindu scholars. From this conference, the first international conference in an Arab country dates the systematic renaissance of science associated with Islam. The theme of the conference was observational astronomy. Al Mansur was interested in more accurate astronomical tables than available then. He wanted, and he ordered at the conference, a better determination of the circumference of the Earth. No one realised it then but there was read at the conference a paper destined to change the whole course of mathematical thinking. This was a paper read by the Hindu astronomer, Kankah, on Hindu numerals, then unknown to anyone outside India.

The Bakshali Manuscript

In 1881, an unexpected find was unearthed in the village of Bakshali about seventy kilometres from the famous archaeological site of Takshashila near Peshawar. This is a seventy-page manuscript written on *bhoorjapatras* (birch bark) in the Sharada script and in the Gatha dialect of Prakrit, which was prevalent in that part of India during the reign of the Kushanas and dates it to around 200 B.C.

The manuscript contains mathematical results of a high order, including quadratic equations, finding square roots of numbers that are not perfect squares, and arithmetic and geometric progressions. The Bakshali manuscript therefore gives a fair idea of the advanced level of arithmetic and algebra in India of two millennia ago.

The Vedanga Jyotisha

Of the six parts of the Vedas *(Sad-Vedangas),* the sixth, Vedanga *Kalpa,* contains the *Shulva Sutra.* The word *kalpa* means rituals, and we have already seen how geometry and mathematics in general evolved as applied knowledge in the context of the rituals of yajnas. The fifth Vedanga, the *Vedanga Jyotisha,* is the earliest known astronomical text from India. It is generally ascribed to the sage Lagadha.

Astronomy provides us with a method to date the text. The earth spins on an axis at an angle of approximately 67 degrees with the plane of its orbit around the Sun. This axis currently points in the direction of the star Polaris, called *Dhruva* in Indian nomenclature. Because of the earth's spin, the stars in the sky appear to move from east to west. Dhruva is an exception for obvious reasons: As the earth spins, its direction in the sky stays fixed because the axis of spin points towards it.

However, while day-to-day observations suggest that the axis of Earth's spin does not change its direction, long-term observations indicate that the spin axis precesses—much like the axis of a spinning top. The spin axis describes a cone in space, and the time taken to make one round of the cone is close to 26,000 years! Thus a few thousand years ago, Dhruva did not enjoy this special status, nor will it do so a few thousand years from today, as the earth's spin axis will no longer point in its direction. It is estimated that the star Alpha Cephei will have that privileged position some 5500 years from now, just as the star Alpha Draconis enjoyed this status 5000 years ago.

These changes in the view of the starry heavens provide us with a long-term calendar, in the sense that there is a slow but steady change of the constellations seen at different seasons on Earth. The text prepared at the time of Lagadha records that the winter solstice was at the beginning of the constellation Shravishtha (Delphini), that is, the Sun was in that constellation on the shortest day of the year. Likewise, the summer solstice was at the midpoint of Ashlesha. Now Varahamihira, who came much later (c- A.D. 530), has stated that in his time the summer solstice was at the end of three quarters of Punarvasu and the winter solstice was at the end of the first quarter of Uttarashadha. Thus since Lagadha's time there has been a shift or precession of approximately 23°20' in angle. A one degree shift takes approximately 72 years, a shift of this amount will take 1680 years. Thus Lagadha would have been 1680 years prior to Varahamihira, bringing the time of the *Vedanga Jyotisha* to around 1150 B.C. This method of dating is not very precise, and allowing for the uncertainties of interpretation, the date may be placed somewhere between the fourteenth to twelfth century B.C.

Likewise, the Indian nationalist leader Lokamanya Bal Gangadhar Tilak (1856-1920) attempted to determine the antiquity of the Vedas by applying this method to the Vedic references to seasonal constellations. His monograph Orion describes this scholarly work, which resulted in his dating the Vedas to around the sixth millennium B.C. Although this method of astronomical dating is precise, the date yielded by it is generally considered to be too early by most scholars. The discrepancy with regard to other methods of dating may be traced to the rather imprecise or ambiguous nature of astronomical allusions available to Tilak.

The *Vedanga Jyotisha* does provide timescales and calendric data that must have been very useful to the societies of the time which set great store by yajnas to be performed at the pre-appointed times. The calendars used the motion of the earth round the Sun, which defines the sidereal year, and the motion of the Moon round the earth, which defines the synodic month. Thus the *Vedanga Jyotisha* mentions that a *yuga* consists of 5 solar years, which equates to 67 lunar sidereal cycles or 1830 days. It can also be defined in other time spans, but discussion of calendars will take us far from the main theme of this chapter. Suffice it to say that the sophistication of calendars prepared by a civilization reflects the maturity of its appreciation of time measurement in the context of a cosmic background.

Even in the pre-Vedic cultures the need was felt for calendars linked to astronomical configurations. Even knowledge of the solar and lunar eclipses, their prediction in advance of the event and their repetitiveness (such as the saros cycle of the Greeks) was available to these early folk dating back to the fourth millennium B.C. According to the Rig *Veda,* priests of the Atri family possessed this knowledge.

There has been the criticism from some Western scholars that the descriptions in the *Vedanga Jyotisha* are too sketchy and vague to mean anything significant. The oral transmission of texts across generations may well be responsible for corrupting the original information, and the emphasis on rote learning and memorization would have gradually effaced the original knowledge and motivation. Nevertheless, what has been so far interpreted and understood emphasizes the importance of the *Vedanga Jyotisha* as an early text that reflects the knowledge of our Vedic ancestors.

From Aryabhata I to Bhaskara II

We now come to a later era, when more was available by way of documents to tell us about the development of astronomy in India. The beginning of this era was in the fifth century A.D., with the seminal contributions of the mathematician and astronomer Aryabhata I (c. 476 B.C.). Unlike most ancient manuscripts in India, a verse in the *Aryabhatiya* by Aryabhata tells us the year of his birth in terms of the prevailing calendar.

In the modern calendar, the birth year works out as A.D. 476, with the *Aryabhatiya* itself being written in the year A.D. 499. The book reflects the level of advancement in astronomy in fifth century India. Aryabhata gives a table of the trigonometric sine functions, calling them *jya* in Sanskrit. The table gives the sines of angles at intervals of 3° 45'.

The sine tables are needed to work out the geometrical measurements of positions of stars and planets on the celestial sphere- Thus we see that Aryabhata was conversant with the notions of spherical trigonometry. Moreover, at the conceptual level, his awareness of the spherical shape of Earth and its spin around an axis reflect how advanced he was with respect to his contemporaries. For example, he argues in one verse of the *Aryabhatiya* that although the stars appear to go westwards, they are in fact fixed and we are observing them from the moving platform of the spinning Earth.

Unfortunately, the sociology of science teaches that while it is creditable and rewarding to be slightly ahead of your contemporaries, it is much more creditable but not at all rewarding to be way ahead of them. For then they do not understand what you are saying and may ridicule your ideas. This happened to Aryabhata, who received ridicule for his views from both his contemporaries and astronomers of later generations. See, for example, what the seventh-century astronomer Brahmagupta had to say about Aryabhata: ‘Since Aryabhata knows nothing of mathematics, celestial sphere or time, I have not mentioned separately his demerits.’

This is strong language even by modern standards of scientific controversy! The prevailing geocentric view (perhaps a Greek influence) did not allow one to think of the alternative of a spinning Earth. So Aryabhata’s ideas remained buried and were long forgotten by the time the heliocentric view of Nicolaus Copernicus (1473-1543) became accepted. Brahmagupta, however, was an excellent astronomer in his own right. His works were translated into Arabic by Abu Rayhan Muhammad ibn Ahmad Al-Biruni (973-C.1050), considered one of the most learned scholars of the Islamic world, whose works were translated as the *Sindh-Hind* (a translation of the Brahma Siddhanta) and the *Alarkand* (a translation of the *Khadakhadyaka).* He was also a good instrumentalist, and in the days of pre-telescopic astronomy he devised numerous aids for observations of the cosmos.

The Jain mathematician Mahavira in the court of the Karnataka Rashtrakuta king, Amoghavarsha Nrupatunga (A.D. 815-878) wrote the Ganita Sara Sangraha, with many beautiful results from mathematics and problems to solve. He is also credited with computing the area of an ellipse (called by him *ayata vritta)* with major axis *la* and minor axis *2b* as Л ab. His formula for the circumference—square root of $(4a^2 + 6b^2)$—is incorrect but a good approximation to the correct answer, which involves an elliptic integral.

It will take us too far out into the garden of mathematics and astronomy if we keep discussing such results by Mahavira and other Indian mathematicians. Let us wind up the discussion with Bhaskara II, a mathematician of the twelfth century, who was both a mathematician and astronomer. One example of Bhaskara’s work will suffice to illustrate the depth of his mathematical ability.

In 1657, the famous French mathematician Pierre de Fermat sent a problem to his friend Bernard Frenicle de Bessy. The problem asked for solutions of the equation

$61X^2 + 1 = Y^2$

where X and Y are integers. They could not solve the problem, and it was only in 1732 that another great mathematician, Leonhard Eulet, solved it. However, it is now realized that the problem had already been solved in 1150 by Bhaskara II, who gave the smallest such numbers as X = 22,61,53,980 and Y = 1,76,63,19,049. The method is called Chakravala method and is given in Bhaskara's *Siddhanta Shiramani,*

But any account of Bhaskara's mathematical work will be incomplete without mentioning his book of mathematical problems*, Lilavati,* which was supposedly addressed to his daughter of the same name. It is commonly believed that mathematics is a complex subject with abstract reasoning that may appeal to only a select few. *Lilavati* corrects that impression by presenting the reader with attractive problems poetically described and relating to contemporary life. Consider the following example:

The square root of half the total number of a swarm of bees went to a Malati tree, followed by another eight ninth of the total. One bee was trapped inside a lotus flower, while his mate came humming in response to his call. O Lady, tell me how many bees were there in all?

This problem can be solved algebraically by using a quadratic equation, the answer being that there were seventy-two bees in all.

Bhaskara was interested in applying the mathematical techniques to astronomy, and his work as presented in the *Grahaganitarn* and the *Goladhyaya* are the culmination of a series of works in spherical astronomy by preceding astronomers like Aryabhata, Brahmagupta, Mahavira and others. He seems to have been close to developing the idea of calculus, writing formulae (similar to $d \sin x = \cos x\, dx$) that follow from differential calculus. He also seems aware that the derivative vanishes at the maxima or minima of the function, again a concept from modern differential calculus.

Ayurveda

We will end this chapter with a complete change of field: From mathematics and astronomy we move on to the medical and surgical sciences as practised under the name Ayurveda. Medical practice was common in the Indus Valley civilization of c. 3000 B.C., as evidenced from the implements and medicinal objects recovered from excavations. The *Rig Veda* also mentions medical practices. An approach of those times was to assume that ill health was caused by ghosts or other evil entities whose existence was not questioned. Rather the doctor would account for a possible influence of this kind when prescribing medicines. However, it is also evident that a scientific approach to understanding the functions of human body and treating it accordingly also started in the Vedic era. As it was a part of the Vedic knowledge, the study acquired the name Ayurveda (sacred knowledge of life). The ancient knowledge is today available principally from four basic texts, the *Charaka-Samhita,* the *Sushruta-Samhita,* the *Ashtanga-Hridaya* and the *Ashumga-Sangraha,* the most famous of these being the first one.

Charaka is not the name of a single person, but it may be the name of a tribe mentioned in the Krishna *Yajurveda.* The main body of the text of the *Charaka-Samhita* is believed to be written around the seventh century B.C., around the time just preceding

Buddha, although it would have contained knowledge known and in practice much earlier. It divides the medical studies into eight parts: surgery with implements, minor operations performed with superficial pricks, medical treatment of bodily ailment, ghostly treatment (of the kind mentioned above), medicines relating to diseases of women and children, treatments of venom and bites, chemistry for maintaining a healthy body, and ways to improve health and virility. Written with a holistic approach, it emphasizes that a sound mind and sound body go hand in hand. As such, it also stresses aspects relating to mind and morality.

The *Sushruta Samtata* is considered an important work telling us how advanced surgical science was in the olden times. It is difficult to date this volume, although the *Mahabharata* (13.4.54) mentions that Sushruta's father was the sage Vishwamitra. The book describes the history of Indian medical science and states that Sushruta was the teacher of Divodas, the king of Varanasi. It is generally believed that surgical science, though well advanced in earlier times, received a setback with the advent of Buddhism because its stress on non-violence placed a taboo on spilling blood. The *Sushruta-Samhita,* however, became widely known and was translated in many languages in Asia and Europe during the ninth and tenth centuries A.D.

Limitations of space compel us to bring this description to a close. It is true to say that many Ayurvedic medical practices remain un-investigated today. Medical science has made progress through empirical approaches, and it is therefore very relevant to find out if some of the Ayurvedic treatments recorded in the ancient texts can still prove effective today, and if so, why. This will involve systematic investigations. In modem times the issue has acquired some urgency because under the intellectual property rights, India should exert its ownership of medicinal knowledge that originated here and was practised successfully. The recent legal battle for the patent of turmeric has shown that unless vigilance is exercised, we may lose our legitimate rights.

. . . And Red Herrings That Had Best Be Forgotten

In the last chapter we described some of our sources that can legitimately support a claim that our ancient ancestors were scientifically advanced compared to their contemporaries. The Vedic base of astronomy, mathematics, and medical and surgical sciences were foundations on which considerable progress was made up to around the end of the first millennium A.D. We also saw the modern need for research into some of the old medicines as they may have a bearing on the current stress on the intellectual property rights.

However, there is another dimension to this issue. We frequently hear the comment that our ancient ancestors anticipated all that modern science is telling us today and that they possessed technology at par with modern times. There are also claims that the Vedas may be credited with a special type of mathematics (dignified by the name Vedic mathematics) that was not thought of in the West. There are quotations from ancient philosophical texts that are interpreted as containing the basic ideas of quantum theory, string theory, unified field theory, relativity theory—all achievements of modem science. In this chapter we will take stock of such claims.

The Hallmark of Science

Before considering such claims, let us look at the indispensable features that set science apart from the rest of knowledge, for only then can we decide whether a given description falls within the scope of science. Science has evolved as a discipline based on pragmatism so far as its basic assumptions are involved, but it also insists on a critical self-appraisal of its own performance. Based on the assumptions, scientific theories are proposed. A scientific theory is expected to make a clearly worded prediction, often with quantitative details. The more sophisticated a theory is, the more precisely stated are its predictions. By way of an example, the following is a sequence of descriptions about the interaction of the earth and the Moon based on the Newtonian theory of gravitation:

[I] The Moon is falling towards the earth just like an apple dropping from a tree; only because of transverse velocity, it keeps going round the earth instead of falling onto it.

[II] The Moon describes a circular orbit round the earth under the action of the inverse square law of gravitation, which provides the centripetal acceleration to the Moon.

[III] If the earth's mass is M, and the Moon's orbital radius is R, then the time period for the Moon to go round the earth once is given by

T = 2 Л square root of [R^3 /GM]

{G is Newton's gravitational constant.}

[IV] Using the laws of motion and the law of gravitation, one may solve a differential equation to find out the actual orbit of a planet around a star or of a satellite around its planet. The Moon's orbit can then be seen as an ellipse.

[V] Although the effect in the case of the Moon is negligible, when Mercury goes round the Sun, its elliptical orbit slowly precesses. To understand this effect in its entirety Einstein's general theory of relativity is needed.

At the risk of appearing too technical, I have arranged these steps in a particular order. Each step is more precise and demands greater quantitative detail than the preceding one. The sequence represents a march towards greater sophistication in interpreting the earth-Moon interaction. Astronomy, the science devoted to observing and interpreting the heavens, has advanced to such an extent that it imposes tight constraints on theories providing the interpretation. The last step in the above series will underscore this fact. A diversion into history illustrates the significance of this observation.

Newton's law tells us (as per step IV) that a planet orbits the Sun in an elliptical orbit. Unlike a circle, which has all points on its circumference equidistant from the centre of the circle, an ellipse has two focal points that define a line, the major axis. The sum of the distances of any point on its circumference from these focal points add up to the same number. Newton's law also tells us that the Sun is at one of the two focal points. Since the orbit is elliptical, naturally the distance of the planet from the Sun changes during the course of the orbit, returning to the starting value at the end of each round. The point at which the planet is closest to the Sun is called the perihelion. If the planet were orbiting alone, the direction from the Sun towards the perihelion, on the major axis, of course remains fixed in space as the planet orbits the Sun.

At least that is what Newtonian gravitation predicts. And for most planets, which are massive or far from the Sun, this is well borne out. In some cases there may be a small steady shift in the direction to the perihelion, but it can be understood in terms of the gravitational pulls of the other planets in the solar system. There is, however, one joker in the pack) Mercury, which is relatively light and closest to the Sun, shows a shift in the direction of its perihelion that cannot be entirely accounted for by the gravitational pull of neighbouring planets like Venus, Earth, Mars and Jupiter. Around 8 per cent of the effect remains unaccounted for. How tiny is this effect?

During our school days, most of us have used a protractor to measure angles in degrees. It is usually marked in units of one degree, which for all practical purposes is a small enough unit for measuring angles. Now the direction from the Sun to Mercury's perihelion changes by one degree in some 8370 years!

Look at two successive orbits of Mercury. As Mercury completes one orbit, we can identify the point P where it was closest to the Sun (S). The next time around the Sun, where was it when it was nearest to the Sun? Newton's law says that it should again be at P. If it is, then the direction from S to the nearest point in the orbit is not changed from S to P- In reality, the next time round, Mercury is closest when at another point (P'), i.e., the direction has changed from SP to SP. This is because the direction of the major axis of Mercury's orbit is slowly turning.

You may ask, do we need to bother about such a small effect? The astronomer will tell you that we do. For here we are matching a scientific theory with actual observations. And a cardinal requirement of science is that the two match perfectly within the limits set by the measurement accuracy. This discrepancy of Mercury's motion was well authenticated by the mid-1860s, and it showed that the Newtonian law of gravitation was inadequate in explaining it. Did that mean that despite its manifold successes, the Newtonian law of gravitation was not perfect?

U.J.J. Leverrier, a distinguished French astronomer, made a valiant attempt to save the Newtonian theory by arguing that there might be an undiscovered planet close to the Sun, orbiting inside Mercury's orbit whose force of gravity may explain this apparent discrepancy vis-à-vis the Newtonian framework. Indeed, two decades earlier Leverrier had employed a similar hypothesis successfully to understand a discrepancy in the motion of the outer planet Uranus, one which had been bothering astronomers. To explain the anomalous observations he hypothesized that there was another planet beyond Uranus. His prediction on that occasion was confirmed by the discovery of Neptune. Unfortunately, in Mercury's case Leverrier was not rewarded by success. The predicted planet (to be called Vulcan) was never found. Eventually, in the second decade of the twentieth century, the general theory of relativity explained the observations perfectly.

This episode tells us of the high standards set by modern science in testing theories and hypotheses about nature. Even in his time, Newton was a stickler for accuracy and elected to go public with his law of gravitation only after he was thoroughly satisfied by the quantitative checks that he could carry out with the then available observations.

One of the consequences of being a professional astronomer is that one gets bombarded by half-baked theories claiming to disprove or improve upon the established theories like Newtonian gravitation or Einstein's general relativity. I call these theories half-baked because they do not go even as far as stage [I] in the above hierarchy. With the stringent standards set by today's science, one cannot comment on such ideas except to return them to their originators and urge them to work them out to the required quantitative detail.

State of Science in Our Ancient Literature

With this background we return to the claim that our ancestors were as advanced (if not more) in science and technology as we are today. Such a claim, in order to be taken seriously, has to be based on concrete evidence. Evidence could come in terms of artefacts surviving the ravages of time or through manuscripts. The former were helpful in revealing the developed society status of the Harappan Indus Valley civilization. Here development does not mean high technology but a well laid-out town plan and social infrastructure. The ruins of Nalanda in Bihar give a reasonably good picture of an ancient residential university, again with a well-planned infrastructure.

So we have to look at the written evidence, available from the Vedic and post-Vedic literature, which is where such claims emerge from. I am on fairly firm grounds here to state that no such evidence goes beyond stage [I] mentioned in the previous section, if at all reaching even that stage.

What about the accounts in epics like the *Mahabharata* or the Puranas? Don't these descriptions talk about guided missiles and missiles that wreak havoc comparable to modern nuclear weapons? Those who make these claims brush aside demands for quantitative descriptions by stating that such descriptions must have been there but were destroyed in the frequent ravages brought about by invasions of India.

However, even accepting this point to an extent, we can argue at the level of the claim. Modern science certainly talks of nuclear physics and the nuclear bomb. Yet, as any student of science knows, the nuclear force is of extremely short range and was discovered by very sophisticated experimental techniques. It is much easier to discover the forces of electricity and magnetism and to harness them for daily use. So a civilization that knew about nuclear physics would surely have gone through the more easier phase of discovering the electromagnetic theory. If that is so, why don't we find any descriptions of the applications of this knowledge in the *Mahabharata?* For example, today's government seeks to offer at least electricity to rural areas. Why then do we find this basic amenity absent, even in the palaces of the Kaurava and Pandava princes?

Hence gaps like these raise doubts about whether the ancients were advanced in science and technology. A more plausible argument could be that the writers of these volumes had wide imaginations, which are reflected in the descriptions of weaponry or magic.

A similar comment may be made on the technology available to the ancients. When we purchase an electric gadget suitable for the household, it comes with a manual of instructions on how to use it. Such a manual, however, does not tell us how to build the gadget. For that a different type of manual would be needed, accessible to those in the factory where it is made or serviced. The real knowledge about how to make the gadget is not to be found in the attractively prepared user's manual.

Take the case of an aeroplane. It is a complex object, and its construction demands knowledge of technology at a sophisticated level. Suppose an extraterrestrial (ET) from a distant planet wants positive proof that we have working models of planes. Would you send the ET colourful ads of different airline companies showing pictures of planes and passengers? Hardly! For the ET may well dismiss them as creations of our imagination. What will interest it as genuine proof would be demonstration of our understanding of the basic principles of aerodynamics, our knowledge of the engineering design, our usage of material for making the body of the plane, etc. The ET would also need to know the capability of our factories for converting a model into a flying object.

In the same vein, we have to say that a picturesque description of the *Pushpaka Vimana* in the *Ramayana* cannot constitute proof that our ancestors really had the technology for flying. We need a technical description that tells us how to make a plane—the preparation of the alloy that provides such a strong body of the plane, the manufacture of the engine, the fuel and the instructions for the pilot. Short of such descriptions we cannot claim that people who wrote the *Ramayana* or the participants of the *Ramayana* were actually conversant with the technology of flying.

Indeed such detailed manuals are missing. I was once recommended to look through the *Brihadvimanashastra,* supposedly written by Bharadwaja, and the *Samaranganasutradhara,* written by King Bhoja, where such descriptions were said to exist. Unfortunately, I could not find such descriptions there. One source of confusion is that the word *viman* is used to describe an aeroplane and is also architectural parlance for windows projecting from buildings with canopies. Several of the descriptions in Bhoja's book related to the latter meaning and not the former.

On the other hand, consider the metal pillar near the Kutub Minar in Delhi. The pillar has not rusted in over fifteen hundred years although it is mainly made of iron. Clearly it is an alloy of iron and as such its composition is of interest to study. Its durability is a mystery. Thus here is a piece of solid evidence that the knowledge of metallurgy, at least at the practical level, was not insignificant in those days. The composition of the alloy used in the iron pillar may be useful knowledge even today, if it can be replicated.

Ancient Philosophical Ideas vis-à-vis Modern Science

There has been considerable literature highlighting the similarity between the philosophical ideas of the olden days and the theoretical concepts of modern science. Characteristically these similarities are noted at the largest level of cosmology and the smallest level of subatomic particles. This is largely because these limits represent the frontiers of human knowledge. Scientists are ambitious enough to want to make these limits recede further, and they have indeed been successful in doing so. For example, at the end of the nineteenth century the atom was regarded as the ultimate basic building block of matter. On the large scale, the universe was largely limited to our Milky Way, with very few astronomers willing to bet on the existence of other galaxies throughout the universe.

By the end of the twentieth century, the atom was no longer the basic structure. Its nucleus was found to carry protons and neutrons, which in turn are made from quarks. Are quarks then the ultimate basic building blocks of matter? It is hard to accept this premise, given the trend towards smaller and smaller structures. What will the present century add? There are already several esoteric ideas like strings, fractals and branes, which suggest that human intuition can no longer be the guide in this quest.

Astronomers have also enlarged their territory by discovering that there is indeed a vast universe beyond the Milky Way containing a structural hierarchy—galaxies like our Milky Way, groups of galaxies and clusters as well as super-clusters of galaxies. The exciting finding that the universe is expanding came as a shock to many. But several questions still exist regarding the origin, evolution and end of the universe. In short, science is an ever-progressing quest for knowledge in which we are not by any means close to the ultimate answer, whatever that may be.

Against this background, it is perhaps premature for someone with an implicit belief in the premise that our Vedic ancestors knew the ultimate answer, to claim that they had the same ideas as modern scientists. For what modern science talks about today is not the ultimate truth. In the trial-and-error method of searching for the ultimate truth, there are occasions when a wrong turn is taken. Sometimes there are two or more possible ways, but one does not know if one of them is the right one. For example, consider the case of the so-called cosmological constant. It was first proposed by Albert Einstein in 1917 to obtain a general relativistic model of a static universe. When in 1929 the early observations of galaxies showed that the universe is not static but may be expanding, Einstein decided to abandon this term. However, other scientists felt that it may well be necessary for understanding the universe. The term describes a long-range force of repulsion between any two material objects, which varies in proportion to their distance apart. In the 1930s Arthur Stanley Eddington, the leading British cosmologist, and Abbe Georges Lemaitre, a Jesuit priest and cosmologist from Belgium, strongly advocated its use. Afterwards, it fell into disuse but was revived from time to time whenever observations seemed to demand it, only to be cast aside when such embarrassing observations went away! Recently, it has been enjoying a revival. How long the current craze for the constant will last is anybody's guess. Against this background, a claim that 'our Vedic ancestors knew about its existence' would be somewhat premature!

A second objection that can be raised against such 'we knew it all' type comparisons is that the similarity of ideas is very superficial. Thus to claim that the quantum uncertainty principle is contained in our Vedantic philosophy is to do injustice to both ideas. Any philosophical notion of indeterminacy is always at the level of abstract qualitative thinking, whereas the quantum uncertainty is precisely definable in quantitative terms. Unlike the word *uncertainty,* there is no lack of precision in the meaning of its principle. It is very well defined. Examples like these are therefore only scratching at the surface and not getting down to details, numerical ones in particular, so far as the scientific notions are concerned.

A few years ago there were large newspaper advertisements claiming to show that various fundamental discoveries in mathematics, physics and biology followed from certain old Vedic statements. The claim also asserted that a particular statement from the Vedas could be interpreted differently to yield these fundamental results in all three subjects. It is indeed incredible that such basic results in three unrelated areas should follow from the same compact statement. The example illustrates the variation of the oft-quoted maxim 'Beauty is in the eye of the beholder', modified here to 'Meaning is in the eye of the interpreter.' These interpreters can serve science well by predicting discoveries instead of post-dieting them once they have been established.

In short, the claims that all the modern discoveries of science are of Vedic origin do not stand up to scientific scrutiny. In fact, they are counterproductive because they divert attention from the genuine discoveries attributable to ancient India. That our Vedic ancestors had the same scientific curiosity that drives modern science cannot be denied. The questions asked in the *Nasadiya Sukta* of the Rig *Veda* bear a striking resemblance to the questions asked by modern cosmologists. That they were curious about the universe is beyond doubt. But that they knew what modern science talks about today cannot be accepted. In the remaining part of this chapter we will discuss claims of a different kind altogether—claims that seek to ascribe things to the Vedas or other ancient texts but which have a much later origin.

Plagiarism in Reverse

Plagiarism is the act of passing off someone else's writings as your own. A study of our ancient literature reveals what I call inverse plagiarism. In this case the culprit adds to a well-established literary work material of his/her own creation in the expectation that the authority commanded by the work in question will bring acceptability and respectability to the additional material also. In Sanskrit this additional insertion is called *prakshipta,* (something that is thrown in). The originator of the *prakshipta* material does not get any credit of course, but the thrown-in material shares the authority of the rest of the work. It is this aspect that makes the dating and authentication of ancient literature difficult to establish. I can do no better than narrate an incident where I was fooled!

The late R.G. Rajwade, a renowned and experienced expert in labour relations, once brought to my attention some extracts from the book *Shukraniti,* written by the scholar Shukra and believed to be around the Gupta period (c. fourth century A.D.). The verses exhibited a high level of appreciation of the welfare aspects of employment. Thus they laid down rules about provident funds, help to the widow of an employee, making provisions for the same by deducting a fraction of the employee's wages and keeping the amount for a rainy day. Surely, here was an example of" how one could be precise and detailed instead of vague and cryptic.

Take a look at the verses 25-32:

Provision should be made for sufficient leisure during the day and the night and for holidays with pay on all festivals, unless the nature of the job is emergent in which case also the holidays with pay should be granted on the Shraddha day.

Employees should be granted 15 days' annual leave with pay.

In cases of prolonged illness employees, who have put in more than 5 years of service, are entitled to receive three-fourths of their wages, for a period of three months, but after a period of six months, the employer is under no obligation to pay sickness benefit. No deduction should be made from the wages if an employee is sick for one week.

From a servant who has stayed away for a year, a representative {a substitute) should be accepted. If a servant who is extremely competent is ill, he should throughout be paid one half of his salary.

One-sixth or one-fourth of the wages of an employee should be deducted and he should be paid back half or the full amount so deducted after two or three years.

An employee, who has served for forty years, should be paid a pension equal to half of his wages, throughout his life.

And after his death, a family allowance equal to half the amount of his pension, i.e., one-fourth of his original wages, should be paid to his wife, if she is good-natured (i.e., faithful) or to his daughter for her well-being, so long as his son is a minor (i.e., not competent to earn).

In one of my articles I cited this example to contrast it with the kind of statements described earlier in this chapter, where the statement is very brief and cryptic and its meaning depends on who is interpreting it and what the interpreter wishes to read into it. 'Look', I said, 'here is an example of how our ancients could make clear and quantitative statements when they needed to.' Alas, I was corrected by experts, who pointed out that the parts I was quoting from were *prakshipta.* It seems that around 1830 some scholar on the west coast of India had inserted these portions in suitably versified form into the *Shukraniti,* although they essentially described the labour rules prevalent in Bombay under the British East India Company![5] So the moral is not to take at face value the claimed authenticity of a statement just because it happens to be worded in Sanskrit! In fact, detailed cross-checks would be needed to arrive at its true provenance.

What Is Vedic Mathematics?

These words should normally mean mathematics from the Vedas, of the kind we encountered in the first chapter. However, in the popular mind, the phrase has been hijacked to mean a particular piece of work, which is described in *Vedic Mathematics* by Jagadguru Shankaracharya Swami Shri Bharati Krishna Tirthaji Maharaj, one of the foremost leaders of the Hindus.[4] Numerous books and articles have since appeared, most of them written by amateur mathematicians, interpreting the contents, commenting on them and generally extolling its high mathematical content. Here is a typical extract from one such publication:

It contains sixteen simple mathematical Sutras from the 'Vedas' and forms a class by itself, not pragmatically conceived and worked out as in the case of other scientific works, but the result of the intuitional visualisation of fundamental mathematical truths and principles.

First of all, can one say that what Swamiji has described is of Vedic origin? The book was published after the author died, and so we do not have his account of how he came across the information in the Vedas. The foreword to the book is written by an editor, and an account of the genesis of the book is given by Manjula Trivedi, a disciple of Swamiji. Neither of these accounts gives any evidence that the work highlighted in the book is of Vedic origin.

The book contains sixteen Sutras, (rules, results or formulae) and thirteen Upa-Sutras. In the preface, the author claims that these Sutras are contained in the *parishishta* {an appendix) of the fourth of the four Vedas, the *Atharva Veda.* Unfortunately, no authorized edition of the *Atharva Veda* contains these Sutras.

In this context, S.G. Dani, a mathematician at the Tata Institute of Fundamental Research in Mumbai who has written authoritatively on Vedic mathematics,[6] cites an episode narrated by K.S. Shukla, a renowned scholar of ancient Indian mathematics.[7] He recalled meeting Swamiji, showing him an authorized edition of *Atharva Veda* and pointing out that the sixteen Sutras were not in any of its appendices. Swamiji is said to have replied that they occurred in his own *parishishta* and in no other! In short, Swamiji claimed that these Sutras were Vedic on his own authority, without any independent evidence to support his assertion. Alas no one, howsoever exalted, has the right or privilege to add anything supplementary to the Vedas and claim that it is as authentic as the Vedas themselves, or else there is no authenticity left in any claimed part of the Vedas as being original to those works.

The Type of Mathematics

Leaving aside the question of authenticity, we now consider the book itself. If the contents were remarkable in themselves as judged by modern mathematical standards, then we could rejoice in the fact that something of Indian origin (Vedic or otherwise) has turned out to be so advanced.

As an aside, one may compare the notebook left behind by the Indian mathematician Srinivasa Ramanujan and discovered in the Trinity College Library. It contained many important and hitherto unknown results of number theory. Characteristically, many of the results were simply stated as facts by the illustrious author, and the later generations of mathematicians spent considerable time and effort proving them. The results were new and made significant additions to the present literature in mathematics. So here we have a compendium of results that has passed the test of being relevant to higher mathematics.

Judged by this standard, the sixteen Sutras stand nowhere, and it does not require a professional mathematician to tell you so. One needs, however, to get over the popular misconception that tricks and short cuts to arithmetical operations like multiplication, division and finding the square root constitute higher mathematics. There are gifted persons who can do mental calculations with large numbers very fast. Public performances (often pitting them against calculators) are very popular and leave their audiences impressed. There is no question that people who have these computational abilities can boast of a very remarkable skill, but they are not mathematicians.

Real mathematics is not number crunching but the interplay of logical reasoning, starting from relatively innocuous-looking postulates that leads to profound conclusions. Take, for example, Euclid's theorem that the number of prime numbers is infinite. (A prime number is one which has no other divisors except the number itself and one.) For example, the first few primes are 2, 3, 5 and 7, but a number like 12 is not a prime since it is also divisible by 2, 3, 4 and 6, besides 12 and 1. So the question is does the sequence of primes end? In other words, is there a last prime so that any number greater than it is composite, i.e., divisible by a factor other than 1 and the number itself? If such a last number does not exist, then the number of primes must be infinite.

Euclid proved that this is in fact the case by the following argument. Suppose we multiply 2 and 3 and add 1 to the sum. We get 7, and if we try to divide it by 2 or 3, the remainder is 1. The number 7 is a prime of course. But we cannot guarantee that the product of all primes starting from 2 and going up to any level, plus 1 will necessarily be a prime. So Euclid gave this ingenious argument- Suppose, the number of primes is not infinite. Then there must exist a prime that is the largest of them all. Call it P. So, by definition, there is no prime greater than P. Now consider the number obtained by multiplying all primes up to P and adding one to the total. This number is

2 x 3 x 5 x 7x...x P + 1.

This number is clearly not divisible by any of the primes up to P. For, if we divide it by any of these numbers, we will get the remainder equal to 1. Now let us examine whether this number is itself a prime or not. If it is a prime, then we have a contradiction, because this new prime is greater than P, which was claimed to be a largest prime in existence. If the number is not a prime, then it has to be divisible by some number. Such a number will either itself be a prime or will have a prime factor, but in neither case can this prime or prime factor belong to our set of primes going all the way up to P, because none of these primes divide this number exactly. (Recall that they all leave a remainder 1.) So this prime will have to be greater than P. Again we have a contradiction. So the assumption that the number of primes is finite is wrong, and their number is indeed infinite.

This argument demonstrates the power and beauty of logical reasoning that leads to a profound conclusion without number crunching. Notice that although we used the notion of multiplication of a large number of prime factors, nowhere did we actually multiply them out to look at the result!

Thus we can say that although mathematics started out as an exercise involving numbers, it eventually expanded far beyond the original concept, and it is the results that command the widest generality and applicability that get recognition as being profound. Mere number crunching is not considered a significant part of higher mathematics.

The Sutras

Having set this modern perception of mathematics as a backdrop, let us now examine the so-called Vedic mathematics to see what its reach is, regardless of the doubts expressed about its Vedic origin.

First, for some reason alien to the modern practice of mathematics, the statements of the results or methods are stated in cryptic phrases rather than in precise and unambiguous words. The defenders of Vedic mathematics argue that this was done to protect the knowledge from falling into the hands of unauthorized persons. The same argument is generally extended to all the knowledge claimed to be of Vedic origin, which is why the Vedic cantos are free for interpretation by any self-appointed expert today and have been interpreted to mean several different things.

Take the Vedic Sutra in the very first chapter, *Ekadhikena Purvena.* This two-word phrase (literally, by one more than the previous one) is to be interpreted into a mathematical formula. Clearly with sufficient ingenuity one can read almost anything into it. The Swamiji takes over a page to describe what mathematical procedure this phrase leads to. He tells us that it is a method of decimal expansion of fractions of the type 1/19, 1/29, 1/39, etc. However, the procedure, besides being cumbersome, is by no means obvious from the two-word Sutra, If one looks at the procedure described and tries to understand the details, one ultimately comes to the conclusion that it is much simpler to do the sum the old-fashioned way taught at school!

Because a lot is read into the Sutra by the interpreter, it is not surprising that another interpreter can also extract a different meaning from the Sutra or that one interpreter can extract several meanings from any Sutra. For example, Swamiji also uses the Sutra to calculate the square of numbers ending in 5, e.g., 25, 35, 75, etc. The trick here is that the number preceding the last 5 is multiplied by 1 more than itself and then 25 is written after that. Thus the square of 25 is obtained by first writing the product of 2 (in 25) with 3 (that is, one more than 2) to give 6. Then we write 25 after 6 to get the final answer as 625. This trick is well known, and with the help of elementary algebra it is not difficult to explain it. It has, however, limited validity, in the sense that it works only for numbers ending in 5. We cannot use it for finding the square of, say, 36. However, why the phrase containing just two words could be interpreted to describe the above procedure as well as the more cumbersome procedure to work out a fraction like 1/19 in decimal form is anybody's guess.

In fact, a look at all the sixteen Sutras and their Upa-Sutras, where they exist, shows that their names have very wide-ranging and vague meanings, thus leaving considerable leeway for interpretation. For example, the Upa-Sutra to the twelfth Sutra is called *Vdokanam* (observation). Observation of what and in what manner? It is up to each interpreter to decipher the hidden purport in this phrase.

In the previous chapter, we highlighted the knowledge that is definitely associated with the Vedic times, such as in the *Shulva Sutra* and the *Vedanga Jyotisha.* There is still more to be found in such sources. However, the level of understanding of those days can be gleaned from such sources, and one must conclude that Swamiji's Vedic mathematics does not fit into the scheme.

For example, the decimal expansions of fractions for which the Swamiji's Sutras are supposed to provide short cuts were not in use in Vedic times. Decimal expansions are relatively recent, dating back to the sixteenth century. How then did these Sutras talk about such expansions? If it is claimed that these expansions were indeed known to our Vedic ancestors, then why are there no references to them in not only the Vedas but also subsequent literature, including that in the much later era from Aryabhata to Bhaskara? Here the defence would be that the knowledge was lost and has resurfaced only with its discovery by the Swamiji. Readers may form their own assessment of the credibility of such a claim.

Given that what has been claimed as Vedic mathematics is no more than an assortment of tricks to do certain limited computations somewhat faster than by the normal method, one may ask whether it is of any practical value. These tricks of the trade may be part of the fun of playing with numbers, and they may also be used to encourage children to find out why these methods work and thus learn a bit more about the algebra of decimal manipulation. But if one is looking for possible practical use in providing fast answers to numerical problems, then I would recommend using a pocket calculator.

The sad aspect of this issue is that in our aspirations to demonstrate a highly developed past, we have bloated up this particular work so much that genuine Vedic mathematics stands neglected. Pressures to introduce Swamiji's Vedic mathematics into the school curriculum will divert attention from the real worthwhile aspects of mathematics that need to be taught. I hope saner views will prevail before long.

3. The Role of Ancient Indian Universities

The Vedic era was known for rishis (sages) who individually propagated learning by opening schools around their homes. The students lived there as part of the extended family of their guru. They would do menial work in the house in exchange for instruction. The teacher's house would provide them with food and shelter besides education, for which they would offer a gurudakshina (an offering to the teacher) at the end of their studies.

This family-based teaching system, commonly known as gurukul (family of the guru), evolved towards institutionalization over time. Very likely the different sages elected to live in communities by the side of a river, and these communities later became what we today call universities. We know of many European universities like Oxford, Cambridge and the Sorbonne as very old educational foundations. Indian universities predate them but did not survive because invading hordes destroyed them. The destruction was of two kinds. Firstly, it was the indiscriminate type with the intention of getting gold, silver and other valuables stored by these organizations. Secondly, it was motivated by the invaders' feeling of insecurity, namely apprehension that the knowledge base in the institution may one day prove to be a threat to their religion or ideology.

We shall visit a few such universities of old, firstly to see how well established the instructional system was and secondly to underscore the fact that its institutionalization was similar to the present university system, which is supposed to be of Western origin, although it preceded the old Western universities by several centuries.

Takshashila (c. 800-450 B.C.)

Takshashila, in the north-west corner of the subcontinent (now near Rawalpindi, Pakistan), appears to have been the earliest of these. Situated in the fertile valley of the Jhelum and Sindhu Rivers, it was a major town in the state of Gandhar, founded, according to references in the *Ramayana,* by King Bharata in the name of his son, Taksha. Records show that by 800 B.C., the university was functioning well. When Alexander's armies came to the Punjab in the fourth century B.C., Takshashila had already developed a reputation as a seat of learning for Hinduism. Thus on his return Alexander took many scholars from there with him to Greece.

Although Takshashila attracted students from all over the country and beyond, it was not yet a university in the currently accepted sense. Rather each teacher was an institution unto himself! What he taught was altogether his business, and students would decide whether they were interested in such topics of study. Chanakya, Dhaumya Muni, Nagarjuna and Atreya were teachers under this system. The system was one of higher education, it being presumed that the student had been trained through the lower rungs of the educational ladder elsewhere before applying to Takshashila. Thus the typical age of a new student entrant at Takshashila was about sixteen.

The university did not operate a common syllabus for any subject. Nor was there any formal examination at the end or a degree for those who passed out. The student's learning was gauged by the reputation of his guru. It was under this system that Chanakya taught Chandragupta, who went on to found the Mauryan Empire.

There were no financial, social or other barriers for entry to Takshashila. Unlike the Vedic tradition wherein' only high-caste men qualified for higher education, here students of all castes studied side by side. There were differences in the students' living styles though. Those coming from nobility and aristocracy lived in special hostels, while the less well off lived with their teachers and helped with household chores while studying. Often the kings paid in advance handsome amounts in cash or through grants of land to the gurus by way of gurudakshina for their sons. The latter mode made the teachers into rich landowners.

Takshashila was a university in the sense that it provided education in a wide variety of subjects, including arts, literature, music, philosophy, religion (both Hindu and Buddhist), law, chemistry, biology, medicine, astronomy, architecture, sculpture, history and geography. It provided instruction in vocational subjects like archery, elephant riding, agriculture, accounting and astrology. There were even courses on sorcery and witchcraft, handling snakes and dealing with omens. Because of its international reputation, Takshashila used to host conferences in medicine and other fields that attracted scholars from Babylon, Syria, Arabia, Phoenicia, China and Persia.

However, being near the north-west frontier of India, Takshashila had to face the brunt of attacks and invasions from the north and the west- Thus the Persians, Greeks, Parthians, Shakas and Kushanas laid their destructive marks on this institution. Takshashila did its best to bear them and had to adapt and evolve with the changing environment. The final blow, however, came from the Huns who, A.D. c. 450, razed the institution. When the Chinese traveller Huen T'sang (A.D. 603-64) visited Takshashila, the town had lost all its former grandeur and international character.

Varanasi

Founded on the confluence of the rivers Varana and Asi in today's eastern part of the state of Uttar Pradesh, this ancient city got the name Varanasi, which later became corrupted to Banaras under the Muslim influence and to Benares under the British Raj. Ancient Hindu literature also refers to it as Kashi. Unlike Takshashila and some other ancient universities described in this chapter. Varanasi has maintained a continued existence and reputation as a place of learning for over 3000 years. It is the holy city of the Hindus, and its situation on the small stretch of the Ganges where it flows south to north gives it a specially holy status. Buddha, after receiving enlightenment, came here to deliver his first sermon to four students. This location, called Samath, about 15 kilometres from Varanasi, has a special status in the Buddhist religion too.

Varanasi has remained a holy place almost from early times. Because of its association with Lord Shiva, it had been a hallowed place for the indigenous Dravidian population. With the Aryan spread into north India, it acquired a special place for them too. Because their seventh and twenty-third Tirthankaras (Suparshvanath and Parshvanath, respectively) were born here, the Jains also revere the city. Several philosophical disciplines were born here. The first name in surgery, Sushruta, lectured and taught here. The original Shankaracharya had to work hard to establish his ideas in this city of learning so that they could gain wide acceptance. In modern times, Pandit Madan Mohan Malaviya established here Banaras Hindu University (BHU) in 1916. BHU may be looked upon as the modern end of a three-millennium-long tradition of education and learning at Varanasi.

However, because Varanasi concentrated in the early times on religious instruction, those who were interested in secular subjects felt the need to go to Takshashila, more than a thousand kilometres away. In fact, many who taught at Varanasi were graduates of Takshashila. The general belief, however, was that for the practical aspects pertaining to life, one should study elsewhere; Varanasi specialized in the philosophical issues pertaining to the life hereafter.

Being fairly out to the east, Varanasi escaped the kinds of raids that Takshashila had to face. However, when in the thirteenth century the Muslim invaders under Kutubuddin Aibak reached as far east as Varanasi, several temples and other places of worship in the city were destroyed, and traditional knowledge faced great threats. Several pandits from Kashi therefore moved south. However, later when Allauddin Khilji's troops ran southwards too, the pandits decided not to run any farther but to resist foreign domination. So in the sixteenth century, several of them moved back to Varanasi and revived the early traditions.

Nalanda

There were many other institutions of learning in ancient India. Kanchi at Kanjivaram played a role in the south similar to that of Kashi in the north. From the second century B.C. to the thirteenth century, this original capital city of the Chola kings played host to scholars from all over India. Huen T'sang, however, devoted a considerable part of his writings to Nalanda, a university in today's Bihar, and it is basically to those writings that we owe our present perception of what Nalanda might have been like in its heyday. He has described this university city as a confluence of Hindu, Jain and Buddhist religions. Chanakya, the teacher of Chandragupta, founder of the Mauryan dynasty and author of the classic volume *Arthashastra,* a Sanskrit text outlining theories and principles of governing a state, was born here and scholars like Nagarjuna, Buddhaghosha, Aryadeva and Jyotipala taught their various disciplines to a long line of pupils. Nadiya (Navadveepa) in the east under the Sena kings of Bengal, Gunasheela in Rajagriha (Rajgir) of Bihar and Shriparvata (Shrisailam) in the Guntur district of Andhra Pradesh are some other centres of education.

No account of the ancient universities in India would be complete, however, without Nalanda. The town is not very far from Rajgir in Bihar. Today its ruins hardly give any feel of the prosperity it enjoyed between the fourth and thirteenth centuries. Vardhamana Mahavira spent fourteen years of his life propagating the Jain religion here. Buddha himself had spent time here, and Nalanda is known as the place of Buddha's triumphs in religious disputations over two scholars, Upali Grihapati and Deegh Tapasi, who subsequently joined the Buddhist faith. A series of famines in the post-Buddhist times, however, compelled a large population, including the scholars, to leave Nalanda.

It was not until the times of Emperor Ashoka that Nalanda began to regain its lost reputation. Ashoka in fact built a *vihara* (Buddhist monastery) to commemorate the birth of Buddha's favourite disciple Sariputta, who had been born at Nalanda. One may consider this as the beginning of Nalanda as a university. Fahiyan, a Chinese traveller to India in the early part of the fifth century, had mentioned Nalanda in his writings about India, although not stressing its importance as an educational centre. Perhaps Buddhism had not yet greatly influenced the place, which in fact happened in later centuries.

In fact, the destruction of Takshashila in the fifth century A.D. created a void that Nalanda very ably filled, and it thereby acquired a premier status amongst the centres of education in India. The Chinese descriptions are indeed glowing in terms of the physical well-being and the intellectual heights attained here. The campus had a very pleasing appearance, with gardens and palatial buildings, baths and playing fields, ponds and streams for boating, and lotuses in abundance. Huen T'sang talks of towers rising to be engulfed in morning fog, monks living in four storeyed hostels with observatories on the roofs of tall buildings, and good workmanship on the terraces.

The entire campus was surrounded by a protective wall. The wall towards the north, for example, was sixty-two metres long and two metres thick with excellent brickwork that left no gaps or revealed any joints. Although the Gupta kings followed the Vedic Hindu religion, they treated Buddhism with respect and patronized Nalanda. Later Emperor Harshavardhana donated much land to the university. There are records of people in nearby towns and villages providing food and commons to the university. Between the ninth and twelfth centuries, the Pala kings also supported the university, although the major donor was King Devapala in the ninth century, who created many modern amenities on the campus. Later kings had their own political problems to face and could not patronize the university to the extent they may have wanted to do so.

Unlike Takshashila, which ran more or less on the individual initiatives of its teachers, Nalanda was organized more along the lines of a modern university. It had a management council and 'an academic council with respective responsibilities towards the overall administration and academic planning. A vice chancellor *(kulapati)* managed the former on a day-to-day basis on behalf of the management council. The academic council had as its members distinguished scholar-teachers, who not only looked after the academic issues of Nalanda but also of its sister institution Vikramasheela located about 30 kilometres away. In fact some teachers had joint appointments at the two universities.

Of the six viharas of Nalanda, each had a supervisory committee, which also included officials like Viharapal or Viharaswamy, whose status was immediately next to that of the vice chancellor. For stressing their identity in any legal matter, Nalanda and each of its viharas had their own seals. When Huen T'sang spent time here, there were ten thousand pupils at Nalanda, which he describes as an educational institution that had no equal. The number of teachers was close to fifteen hundred, thus having a 7: 1 student-teacher ratio. The students were accommodated in single or double rooms in hostels. The walls of the students' rooms had alcoves for lamps and shelves for books and other personal effects. Women were also allowed to study here, but there were strict controls prohibiting men and women from meeting in private rooms.

The Nalanda library was called Dharmaganja, and it was housed in three buildings named Ratnodadhi (ocean of pearls), Ratnasagar (sea of pearls) and Ratnaranjak (pearls of recreation). The first building was nine storeys high, and the other two were of six storeys each. The library also undertook to publish new volumes and preserve valuable manuscripts.

The university had a wide range of courses in both religious and secular fields. The former included the Hindu and Jain religions as well as the more predominant Buddhism. Of its two branches, Mahayana and Hinayana, both were covered, although the Nalanda philosophy conformed to the former. Amongst secular studies, the humanities, sciences, mathematics and medicine were taught side by side with fine arts and vocational subjects.

There were no fees for board, lodging and education of the selected students, although the selection process was a tough one. The *dwarapanditas* (scholars at the door) conducted the entrance test, and only 20 to 30 per cent of the entrants passed. Despite this test, there were ten thousand students in residence, which speaks for the urge for higher education in the community.

This student community, which included monks, was disciplined in its behaviour. The monks lived a particularly Spartan life, and Huen T'sang writes that 'in the seven centuries of the existence of this university, there has not been a single case of a monk breaking the rules'. Those who were good at arguments were highly regarded. Because of its reputation for a concentration of experts, many visitors came from far and near to Nalanda to satisfy their unsolved queries.

Modem institutions (especially in India) often derive their reputation from the guidance and direction of a single individual leader, and after he is out of the scene, they begin to deteriorate. Nalanda successfully maintained its primacy for several centuries largely because it had an unbroken stream of excellent teacher-leaders at the helm, like Aryadeva, Kamalasheela, Kamapati, Chandrapala, Dantabhadra, Dhyanachandra, Bhadrasena and Sumatisena.

This superb institution did not die a natural death through deterioration. Like Takshashila it fell (victim to the invading hordes of Bakhtyar Khilji in the thirteenth century, Its sister institution, Vikramasheela, also met a similar end at the hands of the same invader. The buildings, books and manuscripts, as well as the scholars, all were mercilessly annihilated.

Nalanda Revisited

In the mid-1990s when I visited Muzaffarpur and Rajgir in Bihar, I specially requested my hosts to rake me to the ruins of Nalanda. It was on a fine sunny morning on a Sunday that we found ourselves in the quiet surroundings of the ancient seat of learning. Having visited several old but important: relics in the West and Japan, I was hoping to find a similar infrastructure near Nalanda. I was in for a disappointment.

Normally one expects a larger number of tourists to any such site on a Sunday. However, being a government establishment, the tourist office-cum-museum was closed. There was no souvenir shop or even a bookshop where a guidebook on Nalanda could be obtained. How were we to get any information on the ruins that stood before us? Suddenly I spotted a big sign a few metres away. However, here too disappointment awaited us. For far from giving any information on Nalanda and its glorious history, the board carried a stern notice from the government of India's archaeology department threatening the visitors with dire consequences if they did any harm to the relics. But how was the hapless visitor to know what these relics stood for?

As there was no official source of information, we looked around for a human guide. We were in luck's way, but we had to be patient. A solitary guide was explaining the ruins to another group of visitors. He eventually came over and explained to us how the ruins were dug out of a mound that had formed with dust and soil covering the broken-down buildings. He took us round the main vihara. In the courtyard, he explained, fire was used for cooking food, keeping warm and conducting chemical experiments. We saw the granaries and the monks' compact study rooms. Most importantly, he said that as per the ancient description, only a small part of the old university had so far been excavated. Extensive archaeological digging of the once vast campus remains to be done. Indeed it is ironical that we speak with great pride and satisfaction of our glorious past, yet we do so little to preserve and publicize it.

4. What Arrested the Growth of Indian Science in the Second Millennium A.D.?

The era from Aryabhata to Bhaskara (fifth to twelfth centuries A.D.) saw India enjoying a state of science that was advanced compared to that in Arabia or Europe. Scholars like Al-Biruni visited India to learn Sanskrit so that they could translate the works of Brahmagupta and others into Arabic. Europe during the Dark Ages had nothing comparable to offer. Yet why didn't India maintain its momentum in science?

Abdus Salam once put this question in the following form: In the seventeenth century, the Taj Mahal was built in Agra, around the same time that St. Paul's Cathedral came up in Europe. Both are landmarks in architecture and illustrate how advanced the subject was in these different regions. Yet within a few decades England had an upsurge of science initiated by the discoveries of Isaac Newton. India, however, did not have any such development. Why?

A Lack of Patronage for Science

Let us recall the grim fate that awaited the architect of the Taj Mahal, a man whose identity is not reliably known but who is believed to have come from Persia. The story goes that his hands were chopped off by Emperor Shah Jahan to ensure that he did not replicate anything as exquisite elsewhere. Christopher Wren, the architect of St. Paul's, did not face any such fate. Shah Jahan's action illustrates his possessive attitude, namely that his monument should be unique. In short, although his grand desire produced an exquisite piece of architecture, his motive was not such an enlightened one as to promote that type of creativity; rather it was to boost his ego.

It is in the matter of patronage of science that we notice differences between the nobility in India and that in Europe. In the Europe of the fifteenth to seventeenth centuries, some noblemen patronized science just as they patronized the arts. Thanks to such support, budding scientists could set up laboratories and observatories. King Frederick II set up Uraniborg, an observatory for Tycho Brahe (1546-1601) on the Danish island of Hveen. King Louis XIV took over patronage of the 1'Academie francaise in 1672 with a similar purpose, and it remained thereafter under the purview of the head of the French state. In short, because of such patronage, science received status in society, although we must recall that it was still many years before the Industrial Revolution and so there was no demonstrable use of science so supported.

The situation in India did not run parallel to the European one. Royal or aristocratic patronage no doubt existed for the arts, literature and music, but nobody seemed to be aware of the emerging force of science. Since much earlier times poets like Kalidasa flourished because of royal patronage. Later, in the Mogul era, Emperor Akbar's court boasted of the great music maestro Tansen. There were numerous artists in the courts of Rajput kings and the Mogul emperors. But there is not a single case of a scientist enjoying royal patronage.

Complacency and Fewer Demands

A lack of patronage, however, was not the only cause for India's decline in scientific endeavours. In Europe, the climate can be harsh, with extra effort needed for survival in the bitter winters. Such needs generate demands, and demands prompt searches for meeting them. Thus appeal to technology became a way of life in Europe simply for survival. By contrast, in the bulk of the Indian subcontinent, the extremes of weather are not so great and survival is not so difficult. Hence there was less incentive for searches for new technologies. Indeed, one reason why the Europeans were driven to colonization of other continents was because of the need for a balmy climate.

Colonization required going out on long sea voyages in search of new lands. There were many hazards on the way, and many people perished in the process. But in their efforts to survive, people came to appreciate science as a tool. For example, for a ship lost on the high seas with clouded skies, the magnetic compass provided a method of fixing direction. Gunpowder led to the making of guns and smaller firing weapons, which were far more effective than bows and arrows.

Indeed it can be stated with hindsight that it was their failure to appreciate the force of science and technology that led the rulers in India to succumb to the firepower of the East India Company. Although the British played the card of divide and rule with great astuteness, even without it the fight between high and low technology was an uneven one, despite the large human resources at the disposal of the latter. It was the same asset that helped the European settlers to take control of the African and American subcontinents from the natives, who lacked a comparable level of science and technology.

Whereas Westerners used science as a tool to improve their standard of living, Indians in the sixteenth to eighteenth centuries seemed hardly aware of the potential of science. If they were, they did not seem to care. Again it is not hard to find the sociological reasons for this apathy.

The first reason we have already referred to, namely that of balmy weather. There were no great demands on the system for survival, so far as extremes of weather were concerned. There were famines, limited and widespread ones, which claimed many lives. However, here the religious outlook had already created a mindset in which the emphasis was not on life in this world but on the hereafter. So long as one behaved righteously and suffered any privations calmly and bravely, the hereafter promised great happiness. The righteousness also included a simple life with no luxuries and with very few needs. This religious outlook, although it had its merits, took away whatever incentive one may have had towards making one's lot better in the present existence.

The religious taboo on leaving the shores of the country made it extremely difficult for the adventurous to venture on long voyages like those undertaken by Columbus and Vasco da Gama. This also helped foster the attitude that one should find all one's wants in one's own country or else limit them to what is available there.

This passive attitude certainly helped those in extreme poverty to survive and not raise violent complaints of the kind that led to the French Revolution. Indeed, there is a remarkable lack of revolutions in Indian history when contrasted with European history, and such a passive attitude has a lot to do with it. Even amongst the better off, the social perception was and continues to be to respect those who live simply rather than ostentatiously. So if there is no great desire to live in an air-conditioned room at the height of summer, then why would anyone wish to explore how air can be conditioned?

The social structure also contributed to a lack of drive to innovate and create. The caste system with its four major divisions placed the thinkers, teachers and priests at the apex, followed by rulers and warriors, then the farmers and traders, and finally those who provided service. This stratification and taboo on studies by lower castes deprived a large section of the society of education, especially those who were faced with practical problems of day-to-day existence. There was thus a greater premium on theorists than on practical workers. In science, both theory and experiments must go hand in hand if the subject is to march forward. Pure theory with no supporting observations and experiments degenerates into unproductive philosophy (no disrespect meant to philosophers per se). This was another reason why science in India could not proceed further beyond the elementary stages. Even today, a glance at the working profile in basic science in India shows a greater stress on theory than on experiments.

In this context it is worth recalling two episodes from Indian history. Nana Phadnis, the efficient administrator of the eighteenth-century Maratha rulers, the Peshwas, wanted to build a bridge on the river Karmanashi near Kashi. Attempts by Indian bridge builders failed as the pillars of the proposed bridge kept on collapsing and sinking. The person in charge initiated religious ceremonies to propitiate evil spirits, but those did not help either. When Nana heard of this, he put a stop to the ceremonies and invited an English engineer named Baker. Baker brought suitable machinery for pumping out water and laying firm foundations and was able to complete the job. In the following century Ronald Ross, a British expatriate, tackled the mystery of the origin and transmission of malaria, which was endemic on the subcontinent from time immemorial. Why should it have taken an outsider to come and solve our problems?

Absence of Professionalism

In the last analysis it boils down to a question of mindset. Consider a tennis match between two very good players of comparable ability. Player A is very aggressive in attitude, questioning line calls, complaining to the umpire and occasionally uttering unacceptable expletives. Player B is a thorough gentleman, never questioning the decisions of linespersons or the umpire and never losing his cool. He is so gentlemanly that if he thinks that his opponent has lost a point because of a wrong line call, he deliberately loses the next point! The crowd thinks A to be the bad guy and may even boo him on occasions, while it admires and applauds B for his nice guy actions. Yet at the end of the day, it is the bad guy who wins and has his names in the record books. The good guy is forgotten and consigned to oblivion. Why? It is the attitude that ultimately matters: a professional attitude whose aim is to win the match even if it means doing so at the cost of good behaviour. For the good guy, it is just a game to be played for pleasure and skill, whatever the result.

This example is not given to denigrate in any way the *nishkam karmayoga* (selfless practice of work) preached by the *Bhagavad Gita*. It is given to illustrate what is a fact of life. In a competitive world, it is the professional approach (which may not necessarily conform to the highest form of ethics) that yields the result. In fact, in the *Gita* Lord Krishna exhorted Arjuna to fight as a professional, not as a nice guy.

In science, professionalism is essential. The search for nature's secrets cannot be carried out in an easy-going manner. Perhaps Isaac Newton was so successful because he was a thorough professional. Although a loner and a recluse, he was as jealously conscious of issues of priority and credit for discovery as he was in ensuring that his solution to a specific problem was complete and as accurate as possible. Like the bad guy of tennis, he was hardly popular amongst his neighbours or scientific colleagues, but he delivered results and was respected for them.

Adi-Shankara (the original Shankaracharya) of the ninth century was such a professional so far as his mission of propagating the Vedic religion was concerned. To this end, he engaged in philosophical disputations with his opponents, who were largely influenced by the then-prevalent Buddhist philosophy; he moved all over the Indian subcontinent spreading his message and is today credited with the revival of the Hindu religion. His approach was not that of a fanatic or a zealot; rather he followed a thoroughly professional path that involved discussing and arguing with his opponents until he could defeat them in disputations and convince them of his point of view.

Persons of his calibre were missing from the early Indian scientific scene, ones who could take the next crucial step to understand why the planets move in the way they do or why a projectile sent up at an angle to the vertical falls down after describing a curved trajectory. Even on the applied side, there seems to have been no incentive from the rulers or clever intellectuals to undertake such worldly problems as how to make weapons more effective or how to add to the comforts of the palace by new devices. Even when the British came on the scene and were still not powerful as a ruling force, their weapons were admired and purchased by the rulers for their internecine warfare. But it does not seem to have occurred to a ruler to set up a local research and development effort to duplicate these weapons or to improve their performance.

Rote Learning

Another aspect of this problem relates to the way learning and teaching were practised in ancient and medieval India. We sometimes proudly boast that the Vedas are Apaurusheyas. That is, there was no human creator of these books of wisdom. They were passed down from one generation to next through oral tradition. So the teacher would have learnt them by heart as a student and would pass them on to his disciples when he opened his own school.

A striking tale of this way of learning is told in the life of Shankara. While he was moving from place to place, engaging philosophers and teachers from other disciplines in disputations, he was told that if he wished to propagate his point of view, he must hold such a disputation with the famous scholar Mandan Mishra. So Shankara went to the town of Mandan Mishra and searching for his house, encountered a group of women washing clothes at a pond. When he asked them where Mandan Mishra's house was, he received this poetic reply: Where the pet birds in cages at the doorstep are found to be discussing whether the universe is with or without permanence that is the house of Mandan Mishra.

No doubt this information was given to Shankara to impress him with the scholarly ambience of the local pandit. And indeed, the first impression of any reader of this anecdote is one of appreciation for the scholar whose teaching was so all-pervading that even the household pets were philosophers. However, viewing from a modern standpoint may make one revise this impression. For why did the birds pick up this jargon? Because they heard it from Mandan Mishra's students. Now birds like parrots may pick up some words if they are oft-repeated in their presence. In short, rote learning at Mandan Mishra's school had produced this effect on the pet birds.

Indeed, rote learning was the mode of study in those times, and while it is useful and essential if traditional knowledge is to be passed down to the next generation, this is not the way knowledge can evolve and prosper. With no additions to it, such knowledge remains static and may become irrelevant. For example, we have already seen that there is no universally accepted and complete version of what is contained in the Vedas. Different persons interpret them differently, some using this indefiniteness to argue that practically everything discovered by modern science today had been anticipated and put to use by our Vedic ancestors.

But apart from the emphasis on reproduction rather than understanding, the oral tradition was detrimental to the progress of science as it is practised today. For science progresses by moving further from the available knowledge base, adding to it with new experiments and new theories. If only what exists is to be taught and practised, where is the scope for anything new? The irony is that it is precisely the same rote learning that is rampant in today's educational scenario. Today's schools stress mugging up the right answers rather than comprehension.

It is customary to glorify our past and to recall our superiority of thought and action over the rest of the world. However, reality may not be so appealing to our collective ego. Even if the reader thinks the above comments too drastic, he or she may do well to be more self-critical and think of any alternative reason for why science did not flourish in India during the last millennium.

The stress on rote learning and repeating what is already known in preference to discovering or thinking originally also led to a rather weak tradition of written manuscripts. This fact was brought home in no uncertain manner when some of us undertook a rather unique project in the history of astronomy in India a few years ago. This project is described in the following chapter.

5. The Search for Records of the Sighting of the Crab Supernova

What is common amongst the following: Chinese court astrologers of the Sung Dynasty, the Red Indian tribes on the American subcontinent and a learned physician from the Middle East, all belonging to the eleventh century? The answer: They were all witnesses to a spectacular cosmic event, which is still unfolding, an event that was first witnessed on Earth on 4 July 1054, but whose aftermath is being studied even today and will continue to be investigated by astronomers in the years to come.

Let us begin with the Chinese, to whom we are indebted for maintaining records that date back nine and a half centuries. 'On a Chi-Chhou day in the fifth month of the year of Chi-Ho reign period, "a guest star" appeared at the south-east of Thien-Kaun measuring several inches. After more than a year it faded away.' What could this event be? How came it to be noticed? What was meant by a guest star?

For answers we have to go back a millennium, to the then prevalent Chinese tradition in which the ruling emperor looked to the sky for any warnings from the Almighty, just in case he strayed from the straight and narrow path of fairness and justice. Lest he had to pay a heavy penalty for inadvertently missing such a warning, the emperor made sure that a careful watch was kept on the heavens. It was the duty of the court astrologer to maintain a vigil and inform the emperor of anything unusual. It was in that context that the sighting of the guest star was noticed and duly recorded. The term *guest star* indicates that the star did not exist in the sky prior to the event; more correctly, it had not been observable before. Similarly, after the event was over, the star seemed to have disappeared from the heavens. The Chinese customarily described such transient objects as guests in the sky. The sighting of this object was also recorded in Japan, where too the astrologers kept fairly meticulous records of the heavens.

Indeed, the star, which had been previously too faint to be seen, became so bright initially that it could be viewed even in daylight for twenty-three days, while at night it was visible much longer, being five times as bright as the planet Venus in the early morning (or late evening) for about six months. When it was at its brightest, one could read by its light at night. The recorded direction of the object points to Zeta Tauri in the constellation of the Bull. What do we see there today?

Of course, by naked eye we do not see anything. An astronomical photograph shows a remarkable cloud-like structure with several filaments sticking out. Because the astronomers who took the first photographs of it thought that it looked like a crab, the object was given the name Crab Nebula. Certainly whatever is going on there now must be still pretty violent, judging by its highly disturbed appearance.

We will return to this remarkable object later. First, let's look at other evidence of its observation. In 1955 William C. Miller, a research photographer at the Mount Wilson and Palomar Observatories, published a leaflet under the auspices of the Astronomical Society of the Pacific, in which he presented evidence that the Pueblo Indians in the south-western United States had witnessed this event and recorded pictorially on rock. The pictures are of two types. One is a pictograph, an image made on rock with paint or chalk (or with a rock that writes like a chalk), and was found in the Navajo Canyon area. The other is a petroglyph, an image chiselled on rock with a sharp implement, and it is from the White Mesa region. In both the pictures, a round object is seen besides a crescent. The crescent is the Moon, but what is the round object near *it.*

From old Chinese records one notes that the Moon was in a crescent shape when the object was first seen and at its brightest. The guest star could have been near enough to the Moon for its identification with the round object in these pictures. Moreover, these pictures were found in places from where the eastern horizon was clearly visible. Bearing in mind that such a sight would have been seen near the eastern horizon, one can attach significance to the locations of these pictures.

Could these pictures represent another more common sight known to observers, namely the occultation of Venus? Miller thinks not, because such an occultation occurs once in a few years and one would therefore have expected many more such pictures in the area. Rather one may conclude that the local tribes were not routinely interested in astronomy but were sufficiently impressed by this particularly rare event to immortalize it on rock.

In 1978 Kenneth Brecher from the Massachusetts Institute of Technology and Elinor and Alfred Lieber from Jerusalem presented evidence that the same remarkable sight was recorded in the Middle East by a Christian physician from Baghdad, Ibn Butan.[1] Although not a professional astronomer or astrologer, Ibn Butan, like his contemporary physicians, was interested in the possibility that diseases on Earth could be related to cosmic events. Ibn Butan's biography was recorded in a biographical encyclopaedia prepared by Ibn Abi Usaybia around A.D. 1242, in which his report is reproduced. Some extracts are illuminating:

One of the well-known epidemics of our own time is that which occurred when the spectacular star appeared in Gemini in the year 446H. In the autumn of that year fourteen thousand people were buried in the Church of Luke, after all the cemeteries in Constantinople had been filled.... As this spectacular star appeared in the sign of Gemini ... it caused the epidemic to break out in Fustat when the Nile was low.

The year 446 H (or A.H. 446) is measured on the Islamic Hegira calendar, which corresponds to the period from A.D. 12 April 1054 to 1 April 1055. This correlates to the period when the Chinese saw the guest star. Ibn Butan seems to imply that this event occurred in the summer and caused the epidemic in the following autumn when the Nile was low. This places the event in the summer of 1054, which agrees with the more precise Chinese date of A.D. 4 July 1054.

We thus have three different sources of information about the sighting of a unique cosmic event, from China and Japan in East Asia, from the American continent in the Western Hemisphere as well as from the Middle East in West Asia. Why are there no records from India or Europe? Why, with its long tradition of writing and preserving manuscripts, did Europeans fail to record this event? Here astrophysicist Fred Hoyle and historian of science George Sarton have independently argued that the religious beliefs in Europe of those days assumed that God had created the cosmos in perfection and as such no new phenomena, like this one, would have been considered credible enough to be documented.[4] Certainly what seemed like the creation of a new bright object would have been difficult to explain. So the scholars in the monasteries might have chosen to ignore what they saw. But what about India?

In India astronomy was flourishing in the Siddhantic golden era, which had started with Aryabhata in the fifth century and continued until Bhaskara II in the twelfth century. Surely such an event would have been witnessed by many at least in some part of the subcontinent, despite the July date falling during the monsoon season. When something so unusual was seen, the astronomers and astrologers would have been consulted. The explanation may be that there was not much of a written tradition in India at the time, the emphasis of scholarship being on reading ancient texts rather than creating new ones.

Nevertheless, my colleagues and I felt that some attempts should be made to trace old records of the period that might contain at least oblique references to the event. I accordingly proposed a project for support by the Indian National Science

Academy (INSA) under its programmes in the history of science. I gained considerable assistance from collaboration with Professor Saroja Bhate of the Department of Sanskrit and Prakrit Languages in the University of Pune. This chapter describes the outcome of our investigations. Before coming to those details, let's review the modern interpretation of this strange event.

The Crab Supernova

Around 1731 the English physician and amateur astronomer John Bevis found a bright nebula in the Taurus constellation. In 1758 French astronomer Charles Messier began his famous catalogue of bright nebulous objects in the sky with this bright object labelled Ml. With its direction matching that of the ancient Chinese records and its physical environment consistent with the remnant of what that event was, astronomers are sure that the guest star did not actually go away but is still around in the shape of its remnant, the Crab Nebula. The approximate distance of this nebula from us is 5000 light years, while the extent of the whole structure is as large as 5 to 10 light years.

So this is what remains today of the event that was witnessed by the Chinese, the Red Indians and the Middle Easterners nine and a half centuries ago. The event is a catastrophic one marking the break-up of a star. The star, in its evolutionary course, burns nuclear fuel in its interior. This process serves two purposes. Firstly, it provides the star with an energy reservoir on which to draw in order to continue shining. Secondly, and more importantly for the star's continued existence, it generates internal pressures that keep the star in a stable equilibrium against its inward force of gravity.

However, at some stage the nuclear fuel gets fully depleted, and the star can no longer keep itself in equilibrium. Its inner core implodes while the outer part (the envelope) explodes, being disrupted by the shock wave generated by the inner implosion. A vast amount of energy and particles including neutrinos are released, which is why the star, now called a supernova, outshines the entire Galaxy, a system containing some hundred billion stars. No wonder the Crab supernova was visible to the Chinese even during daytime.

Our Milky Way Galaxy is expected to have such stellar explosions three to four times a century. After the Crab, two supernovae were seen in the Galaxy, one by the Danish astronomer Tycho Brahe in 1574 and the other by German astronomer Johannes Kepler in 1604. Only three were seen in a millennium because light absorption prevents us from seeing explosions in most of the galactic disc. Nevertheless, astronomers do see and regularly record supernovae in other galaxies.

Search Strategies

With this background, let's return to the project itself and the search strategies adopted. The questions we faced were what, when and how: What kind of literature constituted the material to be searched? When was it written? How should we undertake our search?

Obviously astronomical literature had to be searched, but we could not limit the area of our search to literature in astronomy. The reference we were looking for could as well appear in a literary work, such as an epic or a short poem. It was also likely to be located in a work on the history of India or of a region or of a ruling king. The possibility of the mention of a sudden appearance of a bright new star spreading a certain illness among people could be located in a treatise on medicine or a commentary thereof. (Recall Ibn Butan's interest in the event for medicinal reasons.) Moreover, speculations and flights of imagination arising from the sight of a strange shining body in the sky would not have been out of place in books of folk tales or books on miracles, portents and omens in the Indian ethos.

The literature thus identified for the purpose of the present project was astronomical, literary, historical, medical, religious and cyclopaedic in character. This literature was available in three forms: books, manuscripts and inscriptions. In addition to these primary sources in Sanskrit, secondary sources in the form of monographs, surveys and research articles dealing with relevant matter were also included in the scope of this search. The Jain and Buddhist literature that developed in Ardhamagadhi and Pali languages contemporaneously with Sanskrit also was considered a potential source of information.

To answer the question when, we confined our selection to the literature to a certain period. Since the event of the Crab supernova took place in 1054 B.C., we decided to collect contemporary literary sources. However, we later realized that the description of the event could also appear in the works belonging to the subsequent period, because many Indian authors took delight in imitating their forefathers by repeating, sometimes verbatim, what the latter had said. The span of the period of composition of the literature was therefore extended to the fifteenth century.

Because of the vastness and the complex variety of the literature and its being scattered in libraries throughout the country, the mission of collecting and sifting data began in Pune and fanned outwards. We perused histories of Indian literature, bibliographies and proceedings of national and international conferences, Festschrifts, indices of papers published in prominent Indological journals and similar other works to collect primary and secondary material.

For collecting material from manuscripts, the research team went through catalogues of manuscript libraries both inside and outside Pune. The Catalogus Catalogorum also was consulted for obtaining more information. The five-volume Census *of Exact* Sciences in *India,* proved of immense use for the compilation of astronomical data. In spite of an exhaustive list of books and manuscripts prepared by the researchers, relatively few books and manuscripts were available to them. These included the well-known works like the historical poem *Rajatarangini;* the biographical poem *Vikramankadevacharitam-* the folk-tale collection *Brihatkathamanjari;* the mythology of the future, *Bhavishyapurana;* astronomical works like the *Bhadrabahusamhitai* manuscripts of astronomy and astrology like *Shantisara, Chamatkarachintamani* and *Nakskatrachintarnani',* and the bibliographical Prakrit poem *Kumarapalachariyam.* Eminent scholars like Dr B.V. Subbarayappa, president of the International Union of the History and Philosophy of Science at Bangalore, and Dr K.V. Sarma, the veteran Indologist at Adyar in Chennai, also offered invaluable advice.

Among the works perused at Bangalore and Chennai were the books *Narasamhita* and *Yatraprabandha* and the manuscripts *Mukundavijayaprashasti* and *Jyotisharatnamala.* About fifty books and manuscripts were examined at the Academy of Sanskrit Research at Melkote and the Oriental Research Institute at Mysore. The research group likewise visited libraries in north India, in Rajasthan, Gujarat, Kolkata, Ahmedabad, Patna and Varanasi. We decided not to search Kerala manuscripts as much work had already been done on the Kerala School of Astronomy and the researches by eminent scholars were available in the form of publications.

Results

Our searches did not lead to anything definitive that can stand alongside the Chinese or Japanese notings of the Crab supernova, nor are they even broadly confirmatory, as in the case of Ibn Butan's records. Our scholars, however, had been instructed to jot down any references that were even remotely suggestive of a supernova explosion. Having looked at over twenty such findings, we have short listed them to the following seven, which are translated in English below. Although one has to allow for poetic license, items five to seven may have some relevance to the sighting of a star in daytime, which could be a supernova.

(1) Vyasa warns Dhritarashtra of undesirable consequences of the war:

I have seen the day and night with the Sun, the Moon and the constellations burning and the end of the day not differentiable. This will create horror.

—*Mahabharata, Bhishmaparvan 2.22*

(2) The verse is from the story of Harsha who, during his war expedition, uprooted the idol of a local deity, Parihasakeshavam, which had cosmological consequences:

Deep darkness spread all over the land even during the day. People say that each and every direction was illuminated even during the day when the idol was reinstated.

—*Rajatarangini* 7.1347

This description probably comes closer to that of a total solar eclipse than an exploding star. Nevertheless, we give it here since it talks of illumination (other than from the Sun) during the day.

(3) This manuscript from Alwar Maharaja's library describes a certain event as follows:

On the seventh day there would be tremor caused by the wind and one would notice the sky blazing and burning with the falling of meteors and stars.

—*Jyotishakalpataru* 50.1754

(4) The text describes heavenly events causing calamities on the Earth. The list of such events includes the following:

Falling of stars, the Sun, the Moon, similarly, falling of a giant meteor or a heavenly meteor as well as the sight of a star during the day (are bad omens).

—*Shantisara* 0372

(5) This text describes portents, including the following:

Sight of stars, heavenly bodies and constellations during the day (as a portent).

—*Brihatsamhita* 45, 89

(6) Likewise, this text enlists portents in the same way as above. Two of them are described as follows:

Fall of a meteor during the day and sight of a star during the day (as portents).

—*Sarvabhutashanti* 36.380

(7) The text narrates the story of the Sun god who, in order to destroy the pride of all the gods, assumed the form of all-pervading brightness:

O king, to remove their pride and to awaken them, a bright form with eight horns arose in the sky. It was beyond description. The vast sky which was covered with strings of flames and which appeared in multiple forms was invisible for sinners. Like the central bud of lotus a stream of brightness shot out from the middle of the earth and spread high up along a hundred yojanas rotating in the heaven.

—*Bhavishyapurana, Brahmaparvan* 153.29-31

At first sight these slim findings seem a disappointing end to a quest in the history of science. One may try to rationalize the lack of any specific evidence with the oral tradition of transmission of knowledge on the subcontinent. Thus the practice of writing down some fact or idea and preserving it for posterity, common to Europe, China and the Middle East, was not so common in India. Also the practice of debating at length deep philosophical concepts in preference to experiments and observations must have played a role. Even the written material cannot be authenticated vis-à-vis dates, for in some cases portions from earlier manuscripts were simply copied in later ones, presumably because the author felt that it would enhance the overall credibility of the entire text. In other cases, portions were added later and made to appear to be from the original text. This was done presumably so that the later insertions would command the same authority as the original text.

Nevertheless, we feel that the exercise was worth undertaking. It is by no means exhaustive, and some written notings of supernova sightings not found by us may still be around in stone inscriptions or in Prakrit languages instead of in Sanskrit. A detailed list of material searched by us is available with our report published by the INSA. We encourage other scholars to resume the quest and build upon our findings.

6. Indian Astronomy: Colonial Collaborations

The era from Aryabhata to Bhaskara II described in chapter 1 belongs to the so-called period of Siddhantic astronomy. The word *Siddhanta* means *that whose end is established,* and it implies that the stress during this period was on the mathematical aspects of astronomy. Most likely this development owed its origin to the Greek influence on India following Alexander's invasion. Thus the use of algebra, geometry and trigonometry for calculation of planetary orbits and prediction of planetary position at a specified time were the high points of the texts written during the Siddhantic period.

Although Bhaskara II (born A.D. 1114) was the last of the greats in this period, there were others who continued the tradition after him, such as Parameshwara (1380-1460) of Kerala. The interaction with the Arabs grew towards the end of the first millennium A.D., and the Arabic sources frequently refer to one Kanak al-Hindi who played a major role in promoting this interaction. (The Indian sources, however, do not mention anyone of that name!) His involvement seems to be in the preparation of *Zij-al-Sindhind* (the Arabic translation of *Brahma- Sphuta - siddhanta* by Brahmagupta). Other books that were written at this time were *Karanas,* which sought to simplify and provide practical examples of the formulae proved in the *Siddhantas.*

Let's now consider an important aspect of the period following that of the Siddhantic astronomy. This phase of post-Siddhantic world astronomy actually lacks a suitable name. Arab astronomy is a misnomer because most of the astronomers in this period were non-Arabs. Islamic astronomy is politically incorrect, and in the Indian context factually incorrect as well because contrary to general belief this astronomy was Sanskritized. The more recent term, Central and West Asian astronomy, is rather laboured and spatially restrictive. We may use the term Zij astronomy for this phase, because the main occupation of its astronomers was the preparation of Zijes (astronomical tables). Zijes fall into three categories: Zij-e-Rashadi (direct tables) based on actual observations; Zij-e-Hisabi (calculated tables) obtained by correcting observational tables for errors, precession, etc; and Zij-e-Tas'hil (simplified tables), which were simplified versions of other tables, for example, tables for the moon alone. The Zij period began in the ninth century in Baghdad with the translation of Brahmagupta's Sanskrit works into Arabic, and it essentially came to an end in India with the compilation of *Zij-e-Muhammad* Shafti in 1728 by Raja Jai Singh Sawai.

Jai Singh and the Zij Astronomy

Zij astronomy made its debut in India under the patronage of King Firuz Shah Tughluq, who ruled in Delhi from 1351 to 1388. Arabic and Persian Zijes were copied and commented upon. Several books on astronomy were written during his reign and astrolabes (instruments for measuring the altitude of a star) were constructed. On his orders, an astrolabe was placed on Ferozabad, the highest minar of his capital in Delhi. Abul Fazl (1551-1602), the historian during the reign of Akbar, the Mogul emperor, listed in his Ain-e-Alcbari eighty-six Zijes, from Zij-e-Hipparchus (first century B.C.) to Zij-e-Gurgani (fifteenth century). Abu Mulla Farid Dehalvi, writing in the reign of Emperor Shah Jahan (1627-59), classified all the Zijes compiled to date. Owen Gingerich, research professor of astronomy and history of science at the Harvard-Smithsonian Center for Astrophysics, has pointed out that there were at Lahore four generations of astrolabe makers whose instrument design remained virtually unchanged for a century and a half. This suggests that these instruments were meant for drawing room decoration rather than actual observations. Some of them in any case were too big and heavy for actual use. In addition, Firuz Shah also took steps to Sanskritize instrumentation astronomy. On his orders, Mahendra Suri, head astronomer at the royal court, prepared in 1370 *Yantra-raja,* a monograph on astrolabes. This was the first Sanskrit work exclusively devoted to instrumentation, and it was the subject of many later commentaries. In about 1400, Padmanabha described an astrolabe made to a design different from Suri's and therefore taken from a different source. More importantly, he also described an instrument *(dhruva'bhramana.'yantra)* that measures time by observation of the star group polar fish which includes Alpha and Beta Ursae Minoris. Table 1 lists Sanskrit texts exclusively devoted to astronomical instruments. As one can see from the tables, Siddhantic and Zij astronomies flourished side by side for a while.

Astronomical Instruments a la Jai Singh

From the eighteenth century, we have Raja Jai Singh Sawai's treatise on instruments, *Yantra-prakara,* essentially completed before 1724 but with some additions made up to 1729. His astronomer Jagannatha translated in 1732 Nasir al Din al Tusi's (1201-74) Arabic recension of Ptolemy's *Almagest* into Sanskrit under the title *Samrata'Siddhanta,* adding a supplement that described various instruments. Jai Singh went on to establish a number of pretelescopic masonry observatories. The Delhi Observatory, set up from 1721 to 1724, was followed by a bigger one at his new capital Jaipur (1728-34). He built smaller ones at Mathura, Ujjain and Varanasi between 1723 and 1734. {These dates cannot be stated with greater precision for lack of historical detail.) The Varanasi Observatory was housed in an already existing building; it is probable that Jai Singh renovated an old observatory. Since Jai Singh's instruments and observations have been extensively dealt with in the literature, we shall therefore examine the political and scientific context of his work.

Table 1. Instrumentation texts in Sanskrit

Year	Author (Place)	Work	Instrument
1370	Mahendra Suri (Delhi)	*Yantraraja*	astrolabe
c. 1400	Padmanabha	*Yantra-kiranavali*	astrolabe and *dhruva-bhramana-yantra*
1428	Ramachandra (Sitapur, UP)	*Yantra-prakasha*	miscellaneous
fifteenth century	Hema (Gujarat)	*Kasha-yantra*	cylindrical sundial
b. 1507	Ganesha Daivajna	*Pratoda-yantra* *Sudhi-ranjana-yantra*	cylindrical sundial graduated strip
c. 1550-1650	Chakradhara (Godavari)	*Yantra-chintamani*	quadrant
1572	Bhudhara (Kampilya)	*Turiya-yantra-prakasha*	quadrant
c. 1580-1640	Jambusara Vishrama (Gujarat)	*Yantra-shiromani* (1615)	miscellaneous
c. 1720	Dadabhai Bhatta	*Turiya-yantropatti*	based on Chakradhara's work
1688-1743	Jai Singh Sawai (Jaipur)	*Yantra-prakara* *Yantraraja-rachana*	miscellaneous astrolabe
c. 1690-1750	Jagannatha (Jaipur)	*Samrata-siddhanta* (1732)	translation of *Almagest* with supplement on instruments
c. 1700-60	Lakshmipati	*Dhruva-bhramana-yantra* *Samrata-yantra*	
c. 1700	Nayansukha Upadhyaya	*Yantraraja-risala-bisa-baba* or *Yantraraja-vichara-vimshadhyay*	translation of manuscript on astrolabe by Nasir al Din al Tusi, thirteenth century, Iran)
c. 1750-1810	Nandarama Mishra (Kamyakavana, Rajasthan)	*Yantra-sara* (1772)	miscellaneous
c. 1750-1810	Mathuranatha Shukla (Varanasi)	*Yantraraja-ghatana* (1782)	astrolabe
c. 1736-1811	Chintamani Dikshit	*Golananda* (1800)	miscellaneous

Jai Singh was not a sovereign ruler. As an upper-level *mansabdar* (high-ranking official of the administration) who was paid for his services by allotment of land as jagirs, he owed allegiance to the Mogul emperor. He held his *vatan* jagir (hereditary dominion), which is retroactively called Jaipur. He also held various other jagirs that were granted to him by the emperor from time to time. He came to the throne of Amber in 1699. In 1702-03, when a mere lad of fourteen, he participated in Aurangzeb's war campaigns against the Marathas and acquitted himself well. His epithet *Sawai* (literally, one and a quarter) distinguishes him from his more illustrious ancestor of the same name, who is also called Mirza Raja. (The two Jai Singhs have often been confused.) Jai Singh came of age at a time when the once mighty Mogul Empire had started losing influence and power. His own rise in the court hierarchy was in direct proportion to the weakening of the central power. From 1712 to 1737 he served variously as the Governor of the provinces of Agra and Malwa. He was dismissed from both the posts in 1737. Jai Singh received huge funds from the emperor for enlisting troops against the Marathas, which he divided between the

Marathas and himself, and preferred to spend his time at his capital. He had dreams of making his own peace with the Marathas and carving out a vast independent kingdom for himself. He failed in both the missions, but in 1727 he built a new capital, Jaipur, named after himself.

In its heyday, the Mogul Empire was responsible for creation of spectacular buildings (like the Taj Mahal) and gardens. In the reign of the later, lesser Moguls, the cultural activity in keeping with the general atmosphere of intrigue became haveli (mansion)-oriented. The pastimes of nobility in this period were degeneracy, music and poetry. Jai Singh was an exception. Though not averse to intrigue, he was inspired by the earlier illustrious Moguls rather than his own contemporaries. He stands out as unique amongst Indian rulers in showing interest and support for science. It is significant that Jai Singh's observatories are the only visible astronomical effort in the whole of the Sultanate and Mogul periods.

Jai Singh's interest in astronomy was no doubt genuine. But astronomy was also his refuge, and probably a political statement too. The year 1720 was one of rejoicing for Muhammad Shah because he had just freed himself from the clutches of the kingmakers in Delhi. A grand durbar was held on 25 November 1720, where Jai Singh successfully pleaded for the abolition of jazia, the hated tax on Hindus. It is probably at this durbar (or when Jai Singh attended the imperial court a few months later in July 1721) that Jai Singh took the royal permission for building his observatory. Incidentally, Jai Singh's astronomical role model, the martyr-prince Ulugh Beg of Samarkand, was also a collateral ancestor of the Mogul dynasty. The Delhi Observatory in a way commemorates the reestablishment, with Jai Singh's support, of order if not leadership in Delhi after years of anarchy following Aurangzeb. In a similar manner, Jaipur and its observatory symbolize Jai Singh's own imperial dreams. There is an element of irony in Jai Singh's nomenclature for his astronomical work. *Zij'e'Muhammad Shahi* (completed 1728) is probably the only genuine tribute Raja Jai Singh ever paid to his ineffectual but charming emperor.

Jai Singh's Astronomical Tables

Even more ironically from a scientific point of view, the most remarkable feature of Jai Singh's astronomy is its anachronism. When he came on the scene, the telescope had been in use in Europe for more than 100 years, observatories had been set up in Paris and Greenwich, and many important discoveries made. The telescope was a revolutionary break with the past. It freed astronomy from the physical limitations of the eye and was therefore an instrument of the future. Brass and masonry instruments, on the other hand, had reached a dead end, even if they were no worse than the earliest telescopic instruments. Jai Singh failed to recognize the significance of European developments. There was not an iota of doubt in Jai Singh's mind that he need not look beyond Samarkand for inspiration. To him European developments were either not impressive or were unreliable.

For example, in 1728 when Jai Singh's own observational tables were finally ready, he sponsored a scientific delegation to Portugal. Led by the Jesuit priest Father Emmanuel Figueredo, the delegation left in 1728 for Lisbon and returned a year and a half later in 1730 armed with mathematical books and some instruments, presumably telescopes. He tried the imported instruments and found them wanting. Most importantly, the delegation brought back Philippe de la Hire's (1640-1718) rather inconsequential *Tabulae Astronomicae,* which were prepared at the Paris Observatory and published in 1687 with a revised edition in 1702. These tables were enthusiastically received at Jaipur and promptly translated. Although most of the data in Jai Singh's tables are his own, he did borrow from La Hire technical details on refraction corrections, geographical coordinates of a number of places and probably the equation of time. Very soon it was discovered that La Hire's tables were not the last word. In many places, they did not match the observations. Using the terminology with which he was familiar, Jai Singh attributed these discrepancies to the 'inferior diameter' of La Hire's instruments. He invited Jesuit priests from the French factory {a fortified warehouse) at Chandernagore in Bengal for consultations. Father Claude Boudier (1686-1757) arrived at Jaipur in 1734 and confirmed that La Hire's tables were indeed defective. Jai Singh planned to send another delegation to Europe, but his death in 1743 put an end to his plans.

Jai Singh's choice of Portugal for scientific consultancy was ill-conceived. Its riches had come a long time ago, in the pre-Galilean era, and been spent in Mogul-style pomp and extravagance. Devoid of any scientific credentials whatsoever, Portugal was in no position to offer any enlightenment to Jai Singh because it was by then occupying a back seat in European science. The eighteenth century belonged to France and England, which were engaged in bitter commercial and naval rivalry. Both were great patrons of astronomy because of its utility as a valuable navigational aid. Moreover, astronomy became a fashion among the new rich in Europe. It might have been possible for Jai Singh to emulate the European rich and acquire from Paris or London some good quality instruments and use them visually. Or, using his position at the imperial court, he could have asked for and received astronomical instruments as gifts from any of the trading companies. European sailors and traders would have found it profitable to sell their astronomical instruments to Jai Singh and even educate him on their use, if he had so wished. It would certainly have been a rewarding experience because he would have had the southern skies to himself.

The scientific climate of eighteenth-century India stood in sharp contrast to the one in France and England. Europe needed modern astronomy and therefore developed technology for its sake. Traditional craftsmen were persuaded to make the much needed precision instruments in collaboration with the astronomers themselves. A turning point in history does not look for precedents. Jai Singh's India, on the other hand, had no use for astronomy, modern or medieval. Astronomy here was no more than a pastime and was therefore geared to the available technology. When Jai Singh could not get the desired brass instrument made, he tamely gave in and fell back on masonry, in keeping with the long Indian tradition of building imposing palaces, temples and mosques, although his instruments are less precise than Ulugh Beg's.

Jai Singh's edifice of science did not survive for long. In 1745, two years after Jai Singh's death, Emperor Muhammad Shah invited Father Andre Strobel to come to Delhi and take charge of the observatory. He declined. In 1764 the observatory was severely vandalized when Javahar Singh, son of Suraj Mal, the Jat Raja of Bharatpur, plundered Delhi. More than 150 years later, then the maharaja of Jaipur perfunctorily renovated the observatory to give it a presentable look at the time of the 1911 Delhi durbar of King George V, (The Delhi and Jaipur Observatories are now in a rather dilapidated state and no more than popular tourist spots.) Perhaps the most telling commentary on Jai Singh's dedicated but largely irrelevant scientific enterprise comes from the rather disconcerting fact that his grandson converted the Jaipur Observatory into a gun factory and used his ancestral 400-kilogram brass astrolabe (the *samrat yantra)* for target practice.

European Influence

While Jai Singh's observatories at Jaipur and Delhi today are local tourist attractions, at the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in Pune a copy of Jai Singh's *samrat yantra* constructed as per the latitude at Pune stands as a working testimony to Jai Singh's contributions to astronomy. The instrument is part of IUCAA's science park for schoolchildren, where working scientific models explain the laws of science by providing hands-on experience to the user. The *samrat yantra* demonstrates how it can be used in daytime as a giant sundial, with the shadow of its inclined edge falling on its curved arc. A magnificent civil structure like this does not fail to impress the users, but it also tells them the story of a missed opportunity, which could have facilitated the entry of a good telescope into India in the eighteenth century.

In chapter 4, we contrasted the development of science in India and Europe, offering some explanation as to why the former waned as the latter began to blossom. As an example of the European stress on technology for use in solving life's problems, we may cite the invention of the telescope. In 1608-09 Hans Lipperschey, a Dutch optician, accidentally discovered the telescope as he found his assistant gazing through two lenses at a pretty face across the street. Lipperschey realized that by a suitable combination of lenses, the image of a distant object can be made larger and clearer. And so the telescope came into existence and found the military amongst its most avid users. It was certainly convenient and advantageous to be able to view the enemy's army formations and deployment from afar.

In 1609 Galileo Galilei learnt of this new invention and immediately saw its potential for observational astronomy. Could not the distant heavenly bodies be brought closer and viewed more clearly with this instrument, just like the distant armies? Being practical-minded, Galileo made a few modifications to the original design in order to make the first astronomical telescope. With the main lens hardly one inch in diameter, it may look puny besides today's ten-metre Keck telescope, but its impact on astronomy was revolutionary.

We will not go into details of those early times, except to note that the new facts found by this instrument were not always welcomed. For new information can generate conflict with paradigms that are held sacred but based on earlier, less accurate information. So while the Italian intelligentsia initially rejected the telescope as a kind of black magic, society at large began slowly but surely to appreciate its merits. Eventually the new invention was not only accepted but steadily improved upon with time, and by the middle of the seventeenth century astronomy had a revival in Europe. As the traffic from Europe to India grew, the new ideas and techniques in astronomy began to reach the subcontinent.

So it was that after a gap of five to six centuries since the times of Bhaskaracharya, astronomy began to be revived in India, thanks largely to the interest of French and British astronomers. Let's consider the French involvement during the colonial era of the seventeenth to the nineteenth centuries and then the influence of the British, whose presence in India was longer and more widespread and consequently of greater impact on the subcontinent.

French and British Contributions to Astronomy

In 1687 King Louis XIV of France delegated fourteen Jesuit priests as royal mathematicians to the court of the king of Siam (Thailand). The priests reached Siam in 1688. However, the king was dethroned in a revolution. In the ensuing difficult situation, three of the priests left the country, reached Pondicherry in 1689 and stayed on in India. Of these, Father Jean-Venant Bouchet (1655-1732) worked on geography and Father Jean Richaud (1633-93) on astronomy. The name of the third Jesuit is not known. Richaud measured the latitude and longitude of Pondicherry, observed the zodiacal light, saw a comet in 1689 and, more importantly, discovered in 1689 that Alpha Centauri is a double star system. The credit for the first discovery of a binary, however, goes to Father Fontenay, another Jesuit scientist, who made the observation of Alpha Crucis in 1685 from the Cape of Good Hope, Nevertheless, the Alpha Centauri discovery can be considered the first real astronomical discovery from India.

Guillaume le Gentil came to India from Paris in 1761 and stayed several years. He did important astronomical work on the oceans and also carried out the determination of the longitude of Pondicherry. He published his results in Paris in 1779 under the title *Voyages dans les* mers *de l'inde.*

Le Gentil, however, met several misfortunes in his ventures. He was initially deputed by the king of France on the recommendation of l'Academic royale des sciences to observe the transit of Venus across the solar disc, an event which was to be visible in Pondicherry in 1761. He left France on this deputation, but because of the Seven Years War between England and his country, he had to take several detours to avoid the war zones. When he reached Pondicherry, the date for observing the transit, 6 June 1761, had already passed. Like time and tide, astronomical events do not wait for anyone.

Nevertheless, Le Gentil decided to remain in India to observe another transit due eight years later, on 3 June 1769. However, his patience was not to be rewarded, for when the prescribed date came, the sky was overcast, and no observations could be made. (If it was any consolation, the British astronomers deputed by the Royal Society were similarly thwarted at Madras in their rival attempt.)

When Le Gentil sailed back to France, he was twice shipwrecked en route and arrived much later than expected. He reached Paris after eleven years only to discover that he had been declared legally dead and his property given away to his relatives. The modern-day astronomer may make a dash across continents in a few hours, but he too cannot prevent his observation from being blanked out by a cloudy sky!

John Warren had an equally chequered career but not as unfortunate a one. A descendant of Guillaume de Warren who came to England with William the Conqueror in 1066 and later married his daughter, John Warren had to leave France when the aristocracy was under threat from the French Revolution. From 1791 to 1793 he stayed in England, and then he joined the East India Company to come to Calcutta. In India he did many things of note. In 1801 he discovered gold in what became known later as the Kolar

Gold Fields. In 1805 he became director of the Madras Observatory, where he stayed for six years. In 1807 he determined the longitude of Madras. His important volume *Kola Sankalita (Doctrine of Time)* made Hindu calendars intelligible to the Europeans. He returned to France in 1814 to join the French army and subsequently took up the hereditary title of Comte de Warren.

The French astrophysicist Pierre Jules Cesar Janssen (1824-1907), the founder director of the Meudon Observatory near Paris in 1876, was responsible for the first discovery of astrophysical relevance—the discovery of helium. Janssen had observed the total eclipse of the Sun on 18 August 1868 in Guntur, Andhra Pradesh. After the eclipse he continued observing the spectral lines of a new element in the Sun's atmosphere. Because of its discovery in the solar atmosphere the element is called helium. It was detected in the laboratory only in 1895 by William Ramsay. Helium is the second smallest but the second most abundant element (after hydrogen) in the universe. The simplest and smallest nucleus is that of hydrogen, containing just one charged particle (a proton). Helium has two protons in its nucleus and also two neutral particles (neutrons). Current studies of the universe indicate that hydrogen may have slightly more than three quarters of the mass of ordinary matter while the abundance of helium is close to 23 per cent by mass. All other elements make up the rest of ordinary matter.

Janssen used the spectrohelioscope to observe the Sun's chromosphere, the Sun's reddish-coloured outer atmosphere. Both he and Joseph Norman Lockyer (1836-1920) made important discoveries in solar astronomy in India concurrently, and to commemorate their work, the 1'Academic franchise issued special medals carrying their pictures on opposite faces.

Amongst the several instruments and telescopes of French origin used in India, the most important one was the six-inch telescope of English mount ordered by Captain William Stephan Jacob (1813-62) of Poona from the company Lerebours & Secretan of Paris. Subsequently, in 1850 Captain Jacob took up the directorship of the Madras Observatory, and the telescope followed him there. It had a faulty objective, which the makers replaced in 1852. This telescope was used in August 1852 to observe the crepe (Q ring of Saturn. On 17 April 1861 British astronomer Norman Robert Pogson (1829-91) used it to observe an asteroid. Other French instruments were also used for observational astronomy in India, but let's move on to the British connection, A beginning was made in 1651 by a young Englishman called Jeremiah Shakerley (1626-c. 1655), who happened to be one of the earliest followers of Johannes Kepler (1571-1630), the famous German astronomer who some three decades earlier had arrived at the laws of planetary motions by his meticulous analysis of the planetary data collected by Tycho Brahe. Shakerley wished to record the 1651 transit of Mercury across the solar disc.

From such individual flash-in-the-pan type observations to the installation of an observatory is a major step. The British may be credited with this achievement, although the motive was more an applied one than one of promoting pure science. The Coromandel Coast in Madras was known to be rocky and full of shoals. Devastating monsoons twice a year added to the hazards of shipping, so it was necessary to survey the south-eastern coast thoroughly to lay down relatively safe routes for the many ships that traded in the Bay of Bengal. Accordingly, a well-equipped and experienced surveyor was brought to that part of the country in 1785. He was astronomer Michael Topping (1747-96).

The Madras Observatory (1786)

In 1786, perhaps more by design than chance there was constructed at Egmore in Madras a small private observatory. Its founder was William Petrie (d. 1816), an enlightened and influential officer in the East India Company who later officiated as the Governor of Madras for a few months. The observatory was used by Topping as a reference meridian, and on Petrie's persuasion was taken over by the company in 1790. Two years later the observatory moved to its own campus at Nungambakkam in Madras, where some of its remnants can still be seen. In 1899 astronomical activity was shifted to Kodaikanal, and the Madras Observatory became a purely meteorological observatory. One of the instruments that Petrie bequeathed to the observatory was a pendulum clock by John Shelton. Believed to be made for the 1769 transit of Venus and identical to the one used by Captain James Cook in his voyages, it is still ticking at Kodaikanal, a witness to the advent and growth of modem astronomy in India. In the early years the Madras Observatory not only provided the reference meridian for the work of the Great Trigonometrical Survey of India (GTS), but it also supplied it with manpower and instruments. Britain's increasing overseas involvement required familiarity with the southern skies. Accordingly, in 1843, after thirteen years of painstaking work with the newly acquired transit instrument and mural quadrant {both by London optician John Dolland) and with four-inch aperture telescopes, Thomas Glanville Taylor (1804-48), formerly an assistant in Greenwich, produced the celebrated Madras Catalogue of about 11,000 southern stars. It was hailed by the Astronomer Royal, Sir George Biddell Airy, as the greatest catalogue of modern times. (It was revised in 1901.)

In 1850, the observatory acquired its first fixed extrameridional instrument, a six-inch aperture lens telescope by Lerebours &. Secretan of Paris. It was used by Captain Jacob to show that the then recently discovered crepe ring of Saturn was in fact translucent. (The same discovery was independently made a little later by William Lassel at Malta using a twenty-inch reflector.) The only other telescope at Madras, an eight-inch lens equatorial telescope by Troughton &. Simms, was ordered in 1861. (Both these telescopes are now at Kodaikanal.)

The Madras Observatory had by then already become redundant as far as utilitarian astronomy was concerned. When observatories were built in South Africa and Australia, even the British astronomers lost interest. Norman Robert Pogson's (1829-91) uninterrupted thirty-year stint from 1861 until his death is a tragic testimony to the wasted opportunities at Madras. He was the first astronomer at Madras who did not have any surveying connection. His own neurosis was matched by the Astronomer Royal's imperiousness. Left to himself, Pogson would have liked to extend German astronomer Friedrich Wilhelm August Argelander's survey to the southern skies and work on his variable star atlas. Instead, he was forced to carry on routine, drab, irrelevant observations of transits year after year, which he most obstinately refused to reduce and publish. No new instruments were ordered during Pogson's long tenure. What kept the observatory in working order was the help given by the workshops established by the government's public works department for its own use.

Watching the GTS and the Madras Observatory at work, two native rulers—one in Lucknow in the north and the other at Trivandrum in the south—came forward to extend patronage to modern astronomy. It is not that they strove to update the elements of traditional astronomy in the light of new developments in the West or wanted their subjects to learn new astronomy. Instead, they simply funded British efforts. When the nawab of Oudh (now Avadh in eastern Uttar Pradesh) decided in 1831 to set up an observatory, he asked the Governor General to send one of his GTS officers, Major James Dowling Herbert (1791-1833), as the director. Befitting a nawab's whim, the Lucknow Observatory was equipped with the best instruments money could buy, but it closed down as soon as the novelty of the instruments wore off. The observatory was abolished in 1849 and ransacked in the uprising of 1857. In the meantime all the records of the observatory, reduced as well as unreduced, were eaten by ants. Thus ended a first-class, though unproductive, observatory, which need not have been set up in the first place.

Circumstances attending the Trivandrum Observatory were slightly different. Here the initiative came from the British men of science, whom the king gladly obliged. The observatory was established in 1837 with John Caldecott (1813-47) as the astronomer. Astronomy here, however, met the same fate as at Lucknow. But thanks to Trivandrum's proximity to the magnetic equator and to the Madras presidency, the observatory could do sustained work in the fields of magnetism and meteorology under John Allan Broun (1817-79), along the lines suggested by the British Association for the Advancement of Science.

While positional astronomy was slugging it out at Madras, there was taking shape in Europe the new science of physical astronomy or astrophysics. Spectroscopic and photographic techniques were used in the Indian observations of the solar eclipses of 1868, 1871 and 1872, which attracted observers from Europe also. Janssen, observing the total solar eclipse of 1868 from Guntur, detected a spectral line due to a new element, aptly named helium by the independent co-discoverer, Lockyer. During his posteclipse stay at Simla, Janssen created the first spectrohelioscope, which facilitated daily examination of the Sun. It was the transit of Venus on 9 December 1874 that led to the institutional ization of astrophysics in India. This time the state had no major stake in this new astronomy. The initiative and the pressure came from the European solar physicists, who wanted the benefit of India's sunny days for their research. The government, however, was indirectly interested in the work as it was told that a study of the Sun would help predict the failure of monsoons, then as now India's lifeline.

The Dehra Dun Observatory (1878-1925)

When India-based Colonel James Francis Tennant (later a lieutenant general and president of the Royal Astronomical Society) asked that the government set up a solar physics observatory with the instruments already in India for the 1874 transit, his request was turned down. Yet the government was more responsive when Lockyer used his contacts with Lord Salisbury, the Secretary of the State of India. Salisbury wrote to the Viceroy on 28 September 1877:

Having considered the suggestions made by Mr. Lockyer, and viewing that a study of the conditions of the sun's disc in relation to terrestrial phenomenon has become an important part of physical investigation, I have thought it desirable to assent to the employment for a limited period of a person qualified to obtain photographs of the sun's disc by the aid of the instrument now in India [for transit of Venus observation].

Accordingly, starting from early 1878, solar photographs were regularly taken at Dehra Dun under the auspices of Survey of India and sent to England every week. Dehra Dun continued solar photography until 1925, but more out of a routine sense of duty than enthusiasm. The larger of the two photoheliographs fell into disuse, and in 1898 Lockyer was stung by his on the-spot discovery that bees had overtaken the dome.

St. Xavier's College Observatory, Calcutta (1879)

Sunny India caught the attention of astronomers in the continent also. The Italian transit-of-Venus team led by Professor P. Tacchini of Palermo stationed itself in Bengal, its chief instrument being the spectroscope, an instrument the English parties did not possess. A co-opted member of the Italian team was the Belgian Jesuit, Father Eugene Lafont (1837-1908), professor of science at St. Xavier's College, Calcutta, who though no researcher himself was an inspiring educator and science communicator. The college provided education to the sons of Europeans, Anglo-Indians, rajas, zamindars and Indian men of note. Lafont therefore gained access to people of influence, which he put to good use in the service of science. Tacchini suggested to Lafont that he erect a solar observatory in Calcutta to supplement European observations, which had gaps due to bad weather obscuring the views. Lafont soon collected a sum of Rs 21,000 through donations, including Rs 7000 from the Lieutenant Governor of Bengal. Soon a spacious dome was constructed and fitted with a splendid nine-inch refractor by Steinhill of Munich, complete with a large reversible spectroscope by Browning. The St. Xavier's College Observatory did painstaking if not very striking work, thanks to the customary thoroughness and dedication of the Jesuit men of science. At about the same time there was erected at Poona a research observatory for entirely different reasons.

Takhtasingji Observatory, Poona (1888-1912)

This was the most personalized of all observatories. In spite of its name, it was owned by the Bombay government and was set up for one man, Kavasji Dadabhai Naegamvala (1857-1938). Naegamvala was a brilliant student. In January 1878, he passed his MA examination in physics and chemistry in first class from Elphinstone College, Bombay, and was awarded the chancellor's gold medal, the highest honour of Bombay University. He returned to the college in 1882 to fill the newly created post of lecturer in experimental physics at a monthly salary of Rs 250. When the maharaja of Bhavnagar visited Elphinstone College in October 1882, Naegamvala requested a donation so that a spectroscopic laboratory could be started at the college.

The maharaja obliged, and the government of Bombay matched the royal gift of Rs 5000 with an equivalent grant and sent Naegamvala to England to finalize the equipment in consultation with the Committee on Solar Physics and the best makers of spectroscopic apparatus. While in England, Naegamvala boldly jettisoned laboratory spectroscopy in favour of the celestial one. By advice of the Astronomer Royal, he allotted the bulk of the funds at his disposal to the purchase of a reflector telescope which would be the largest in India. This twenty-inch Grubb telescope remained the largest in India for eight decades, even if half its time was spent in the boxes. In view of the better credentials of Poona as an astronomical site, the observatory and Naegamvala were transferred in 1888 to the College of Science (now College of Engineering) there. Naegamvala was a member of the British scientific team that went to Norway in 1896 to observe the total solar eclipse. For the 1898 eclipse that was visible from India, Naegamvala was given a sum of Rs 5000 by the government to match an equivalent sum raised through donations, ranging from Rs 100 to Rs 500. Qamsetji Nusserwanji Tata contributed Rs 250.) The eclipse brought Sir Lockyer and the Astronomer Royal, Sir W.H.M. Christie, to India at the request of the government of India to report on the observatories here.

The best thing that could have happened to Naegamvala was his being discovered by Lockyer. Lockyer in his report paid glowing tributes to Naegamvala, whom he described as the only person he knew in India who was practically familiar with solar physics work. On Lockyer's recommendation, Naegamvala was relieved of teaching duties, appointed full-time director of the observatory and asked to send data regularly to Lockyer, If Lockyer had had his way, he would have appointed Naegamvala the director of the proposed Solar Physics Observatory at Kodaikanal in place of the Madras astronomer Charles Michie Smith, about whose capabilities Lockyer had a very low opinion. Naegamvala did not go to Kodaikanal, but in 1912 all his equipment was sent there when the Poona Observatory was closed down on his retirement.

Kodaikanal Observatory (1899)

Although the question of upgrading the astronomical facilities at Madras had been brought up off and on in the British quarters, it was only after the death of Pogson in 1891 that the matter was taken up in earnest. It was finally decided in 1893 to establish a solar physics observatory at Kodaikanal in the Palani hills of south India with Michie Smith as the director. All astronomical activity was shifted from Madras to Kodaikanal, and the new observatory was transferred from the. Madras government to the charge of the imperial government's Indian Meteorological Department.

To start the observatory, Greenwich sent on permanent loan a photo heliograph, one of the five identical ones made by John Henry Dallmeyer for the 1874 transit-of-Venus expeditions. The six-inch refracting telescope by Lerebours & Secretan of the 1850 vintage was remodelled and installed for daily photography of the Sun. (This must be one of the oldest telescopes still in scientific use.) The arrival of solar physicist John Evershed in 1907 from Great Britain (as assistant director to begin with) heralded the observatory's golden age. Choosing to come to India, no doubt to work in solitary splendour, Evershed made Kodaikanal's facility into a world-class, state-of-the-art observatory. He put the newly acquired spectroheliograph into working order, made a prismatic camera using the prisms he had brought with him and assembled a number of spectrographs. In 1911 he finally constructed an auxiliary spectroheliograph and bolted it to the existing instrument so that now the Sun could be photographed not only in the light of calcium K spectral line but also in hydrogen alpha. In 1909 Evershed made the important discovery of radial flow of gases in sunspots (the Evershed effect). After Evershed's retirement in 1923, the observatory slowly fell behind the times and became routine-work oriented. It assiduously took solar pictures every day (weather permitting) and exchanged them with other observatories the world over, building in the process an enviable collection of solar pictures that now spans eight complete solar cycles.

Nizamiah Observatory, Phisalbanda (1901)

The positional astronomy slot that fell vacant in 1899 with the winding up of the Madras Observatory was filled by the Nizamiah (Nizam's) Observatory in Hyderabad. Its founder was a rich, England-educated nobleman, Nawab Zafar Jung. The nawab purchased a small telescope and set up an observatory at his estate at Phisalbanda in Hyderabad. Very far-sightedly, in 1901 he took the Nizam's permission to name the observatory the Nizamiah and made sure that it would be taken over by the government on his own death. He subsequently acquired a fifteen-inch aperture Grubb refractor telescope. Curiously, he also obtained an eight-inch aperture astrograph (astronomical camera), which later became the observatory's chief instrument. Zafar Jung died in 1907, and as planned his observatory was taken over by the government. Thus, ironically, the formal establishment of the observatory had to await the founder's death.

The next year the observatory was formally inducted into an ambitious, ongoing, international programme called *Carte du del* (astrographic chart and catalogue). The aim of this programme was to map photographically the whole sky by assigning various celestial zones to eighteen different observatories around the world. The Nizamiah was asked to take over from the Santiago Observatory in Chile, which had defaulted on the (17° to 23° S) zone assigned to it. Finally the observatory also ended up doing the Potsdam zone (36° to 39° N). In the meantime (March 1908), Arthur Brunei Chatwood was brought from England as the director on a monthly salary of Rs 1000 (about £900 a year). Chatwood's tenure was far from being a success. He did not go beyond the installation of the astrograph at the new site of Begumpet and quit in 1914, unlamented.

Astrographic work could be taken up in earnest only in 1914 with the arrival of Robert John Pocock (1889-1918). Pocock was the protégé of the influential Oxford professor, Herbert Hall Turner (1861-1930), and came directly from Oxford and armed with a special grant. The first usable plate was taken on 9 December 1914, and the first volume of results published in 1917. When the work finally ended in 1946, a total of 7,63,542 stars had been observed and twelve volumes published. These data were in turn used by the observatory astronomers to extract information on the proper motion of stars and on double stars.

Pocock was the last European director of the observatory. On his untimely death in 1918 he was succeeded by his erstwhile assistant, Rao Sahib Theralandoor Panchapagesha Bhaskaran (1889-1950), who had to wait for four years before getting the formal appointment. Bhaskaran was a foundation fellow of the Indian National Science Academy (INSA), established in 1935 under the name National Institute of Sciences of India. (The name was changed in 1970.) In the academy's records his name appears as T.P. Bhaskara Shastri.

Apart from the astrographic work, the Nizamiah had other, smaller, irons in the fire. The fifteen-inch Grubb refractor was at long last installed in 1922 and used for visual observations of variable stars as well as for lunar occultations. The Sun also received some attention, thanks to a Hale spectrohelioscope acquired in 1939. The observatory also did some community service by keeping standard time and preparing government calendars in Urdu and English. Today the observatory is controlled by Osmania University in Hyderabad.

The Indian Response

Just as the British needed a base of modern science in India, so they needed Indians as human resources. Accordingly, the 'natives' were introduced to English education. As the scientific content of the administration increased, they graduated from being clerks and writers to becoming doctors and engineers and finally scientists. In January 1876, Dr Mahendra Lal Sircar, in collaboration with Father Lafont, generated support among Indians as well as in government circles for setting up in Calcutta the {rather oddly named) Indian Association for the Cultivation of Science (IACS). The IACS was the scientific wing of the Indian Association, which was a political organization of educated Indians and a precursor of the Indian National Congress. Its aim was to enable the 'Natives of India to cultivate Science in all its departments with a view to its advancement by original research'. A rich benefactor, Kumar Kanti Chandra Singh Bahadur, presented the IACS with a valuable seven-inch aperture, Men-Browning equatorial telescope in 1880, but it had to wait for more than thirty years to find a user. Observational astronomy simply failed to take off under Indian auspices.

The appearance of comet Halley in 1910 activated astronomy butts in Calcutta, who set up an Astronomical Society of India. There were 192 original members, including scientists, informed laypersons, Christian missionaries and some rich Indian patrons. The first president was Bengal's accountant-general, Herbert Gerald Tomkins (1869-1934), who remained the society's driving force during its decade-long existence. It is not clear whether the society was formally wound up or simply became defunct. The last available issue of the society's journal is dated June 1920. (The name of the society was reused when setting up a new national society at Hyderabad in 1973.)

An active member of the society was Chandrasekhar Venkata Raman (1888-1970), the young deputy accountant-general and part-time researcher at the IACS who quit his lucrative government job in 1917 to take up the newly created Palit Professorship of Physics at Calcutta University. He served the society variously as its business secretary, librarian and director of the variable star section, and he contributed to the journal as well as to the discussions. He installed the association's seven-inch telescope and put it to use. Raman maintained a life-long enthusiasm for astronomy. Another member of the society was a subjudge, Nagendra Nath Dhar (1857-1929), who made optics for telescopes in his workshop in Hooghly and discussed his techniques at the society meetings.

The most dedicated observer of the time worked outside the pale of the astronomical society. Born in a zamindar family in a small village, Bagchar, in Jessore district (now in Bangladesh), Radha Gobinda Chandra (1878-1975) left school after failing three times in the matriculation examination and took up a job as a *poddar* (coin tester) at the collectotate at a monthly salary of Rs 15. His introduction to astronomy came from a Bengali text and practical acquaintance with the sky from his scientific apprenticeship to a lawyer, Kalinath Mukherjee, who was editing a star atlas. He observed comet Halley through binoculars and in 1912 purchased a three-inch lens telescope from London for £13 (Rs 170). He became a regular observer of variable stars and a member of the American Association of Variable Star Observers (AAVSO), which in 1926 gave him a six-inch aperture telescope, originally belonging to AAVSO's patron and friend, Charles W. Elmer. Chandra certainly made good use of it, communicating a total of 37,215 trained-eye observations up to 1954, when he finally retired from observing. The value of his prodigious work lies in the fact that, because he worked at a longitude far from that of most observers, he had could fill in what were otherwise gaps in the observational records for the stars he studied. Chandra was asked to pass on the AAVSO telescope to Manali Kallat Vainu Bappu (1927-82), who was then at Naini Tal. The Elmer-Chandra telescope, one of the very few American telescopes in British India (if not the only one), is now at Kavalur. A rather atypical scientific enterprise in the nineteenth-century British India was a private astronomical and meteorological observatory at Daba Gardens, Vizagapatnam (now renamed Vishakhapatnam in Andhra Pradesh). It was established in 1841 at his residence by the rich zamindar Code Venkata Juggarow (1819-56), who had earlier gone to Madras to take tuition from the astronomer Thomas Glanville Taylor. On Juggarow's death, the zamindari and the observatory passed on to his son-in-law Ankitam Venkata Nursing Row (1827-92), who resigned his job as a deputy collector with the East India Company to look after his wife's estate. In 1874 he furnished the observatory with a six-inch Cooke equatorial, a transit circle and a sidereal clock. These are instruments used by astronomers for accurately specifying the position of a heavenly object in the sky. He communicated his observations of solar eclipses, transits of Venus and Mercury, and comets to British astronomers and the Royal Astronomical Society. He obtained equipment for celestial photography but died before he could install it. He was also the honorary meteorological reporter to the government of India for Vizagapatnam. His son, Raja A.V. Jugga Rao Bahadur (d. 1921), served as the vice president of the Astronomical Society of India for a year (1911-12). The observatory seems to have closed down afterwards. (The site is now occupied by the Dolphin Hotel.)

In passing, we may notice a small telescope with an unusual history. In 1938, the infamous Adolf Hitler presented a five-inch aperture Zeiss telescope to the rana of Nepal. In 1961 his son, the new rana, passed on the telescope to Everest hero Tenzing Norgay, who in turn donated it to the Himalayan Mountaineering Institute in Darjeeling, which he headed.

Although the Indian response to observational astronomy was rather lacklustre, it was path-breaking in the field of theoretical astrophysics. While the well-placed Calcuttan astronomy enthusiasts were forming their society, unknown to them a bright lad in the backwaters of East Bengal was making his acquaintance with astronomy. Meghnad Saha (1893-1956) wrote an essay on comet Halley in Bengali for the Dacca College magazine. As lecturers in physics in Calcutta University, Saha and Satyendranath Bose (1894-1974) brought out in 1920 English translations of Einstein's papers on relativity. Reviewing this work, the science magazine *Nature* wrote on 26 August 1922: 'Provided it is studied with care, the translation will nevertheless be of service to those who are unfamiliar with German, and wish to grapple with the pioneer works on these subjects, some of which are rather inaccessible.'[7]

Stimulated by Agnes Clerke's popular books on astrophysics, Saha published in 1920 his epoch-making work on the theory of high-temperature ionization and its application to stellar atmospheres. Saha's demonstration that the spectra of far-off celestial objects can be simply understood in terms of laws of nature as we know them on Earth transformed the whole universe into a terrestrial laboratory and laid the foundation of modern astrophysics. In 1923 Saha moved to Allahabad University as professor of physics where he set up a school of astrophysics and trained outstanding students like Daulat Singh Kothari (1906-93), a physicist who later became the chairman of the University Grants Commission. In 1937 Saha was the first to point out the need to make astronomical observations from outside the earth's atmosphere. He returned to Calcutta in 1938 as Palit Professor. Saha and Bose, like Raman, were the foundation fellows of the INSA. Saha became its president in 1937-38, Bose in 1949-50, and Kothari held the post in 1973-74.

In Madras, Subrahmanyan Chandrasekhar (1910-95) for the first time applied the theory of special relativity to the problems of stellar structure, and he obtained preliminary results that he would later deduce rigorously at the University of Cambridge a few years later. This would come to be known as the Chandrasekhar mass limit. Chandrasekhar belatedly received the Nobel Prize in 1983.

Curiously, unlike the Indian physicists, pioneering relativists were trained abroad. Nikhil Ranjan Sen (1894-1963), a classmate of Saha and Bose, joined as a lecturer in applied mathematics at Calcutta in 1917- He obtained his D.Sc. in 1921, but went to Berlin where he obtained his Ph.D under the supervision of Professor Max von Laue, professor of physics at the University of Berlin. Sen's was the first Indian doctorate in relativity, and he joined the INSA as a foundation fellow. Vishnu Vasudeva Narlikar (1908-91) obtained his B.Sc, in 1928 from the Royal Institute of Science, Bombay, and left for Cambridge University for higher studies, thanks to financial assistance from Bombay University, Kolhapur state and the J.N. Tata endowment. He passed the mathematics tripos with distinction in 1930 and went on to win the Rayleigh Prize for his astronomical researches under Professor Arthur Stanley Eddington, the Pumian Professor of Astronomy and Experimental Philosophy at Cambridge University. Spurning an offer to go to the California Institute of Technology in the United States, he accepted an invitation from Pandit Madan Mohan Malaviya, the vice chancellor of Banaras Hindu University, to head the mathematics department in 1932, where he remained for the next twenty-eight years. He trained and guided a large number of students including Prahlad Chunilal Vaidya (b. 1918), the author in 1943 of the well-known Vaidya metric for the gravitational field of a radiating star. In 1955 came Amal Kumar Raychaudhuri's (b. 1923) equation that has played a crucial role in the investigations on singularity in relativistic cosmology.

In 1938, B. Datt from Sen's group gave the solution for a gravitationally collapsing spherical ball of dust. It anticipated the more commonly known solution of Oppenheimer and Snyder. The significance of this work was appreciated some twenty-five years later when astronomers began to discover quasars, shining but highly concentrated and powerful sources of radiation. The dense state of quasars is believed to be the end result of the kind of precipitous gravitational contraction that Datt, Oppenheimer and Snyder had envisaged.

By the time World War II came to an end, it was clear that the British rule in India would soon be over. Plans were therefore afoot to set the scientific agenda for the future. As part of this effort, from 1943 to 1945 the government of India made sincere efforts to bring Subrahmanyan Chandrasekhar from Chicago to Kodaikanal. He was offered a salary three times the usual, bur he did not want to oversee the routine work of an observatory and preferred a job in a university. Attempts of a similar kind were also made by Dr Sarvapalli Radhakrishnan at the Banaras Hindu University and Dr Homi Bhabha at the Tata Institute of Fundamental Research (TIFR). Although Meghnad Saha felt that 'Dr. Chandrasekhar ought to return to India to train our own boys', this was not to be.

Twenty years previously, the British director-general of observatories had offered to Saha the number two position under Evershed at Kodaikanal. In December 1945 Saha led a five-member committee including the Indian director-general of observatories to Kodaikanal to prepare a plan for astronomical and astrophysical observatories in India. The Saha Committee proposed updating astronomical facilities including 'the establishment in northern India of an astronomical observatory provided with a large-sized telescope for special stellar work'. The committee's report came in handy twenty years later when Vainu Bappu successfully pleaded for a stellar spectroscopic observatory at Kavalur in Jawadi Hills, Tamil Nadu. (The observatory has since been named after Bappu.) As a follow-up to the report, and on Sana's own initiative, in 1955 a National Almanac Unit was set up at Calcutta to help the traditional almanac makers update their astronomical elements. (The unit was renamed the Positional Astronomy Centre in 1979.)

The year 1945 also saw the establishment of the Tata Institute of Fundamental Research in Bombay- Its founder was Homi Jehangir Bhabha (1909-66), a brilliant physicist who shared Jawaharlal Nehru's vision of a scientific India as well as his aristocratic background through his relationship to the wealthy and enlightened industrial family of the Tatas. (Sir Dorab Tata was married to Bhabha's paternal aunt, Meharbai, in 1898.) An important item on the institute's agenda was experimental research on cosmic rays, in which Bhabha was personally interested. The experiment involved sending payloads attached to balloons into the atmosphere, which led to the advent of space astronomies in India. In fact, Indian's entire space programme was to come out of such initial efforts. Its initiator, Vikram Sarabhai (1919-71), was in turn inspired by Bhabha's pioneering work in India's atomic energy programme. It was also with Bhabha's support that radio astronomy was successfully introduced in the 1960s by Govind Swarup (b. 1929).

A Critique of India's Progress

We can single out three cosmic events from the past two centuries and use them as benchmarks in discussing the advent and growth of modern astronomy in India. The 1769 transit of Venus took place at a time when England and France were engaged in bitter rivalry over India. This brought positional astronomy in India as a navigational and geographical aid. The 1874 transit of Venus saw India firmly in British grip. The new science of physical astronomy was taking shape, and the British scientific activity was commensurate with its economic and political status. Solar physics came to India because the British astronomers wanted data from sunny India and the government believed that a study of the Sun would help predict the status of monsoons. Interestingly, the work plan prepared by the Royal Society for Kodaikanal Observatory in 1901 makes no mention of the solar-terrestrial connection. By the time comet Halley appeared in 1910, India's new middle class had become politically assertive and scientifically ambitious. While the Indians on their own remained mere dabblers in observational astronomy, they were beginning to make original contributions in the fields of theoretical astrophysics and relativity, in which areas they no doubt felt more at home.

At the time of Independence in 1947, India could boast of only two rather outdated observatories—the central governments solar physics observatory at Kodaikanal, which stood where Evershed had brought it in 1911, and Osmania University's non-teaching Nizamiah Observatory with equipment of still earlier vintage. The Saha Committee's rather pious recommendation for upgradation of the astronomical facilities was on record, but there was nobody at hand to drive home the advantage. Bhabha's nascent institute was still housed in his aunt's mansion but poised for take off in a big way. Finally, although the number of universities multiplied, they failed to keep the early promise of advancing astronomical research.

This account of how science progressed under colonial influence in India tells us that the growth of science and technology heralded by the Industrial Revolution in Europe was transplanted by the Europeans to their colonies. However, a transplant does not necessarily survive and prosper unless there is the right mindset to receive it. A parallel social reform was needed to adjust the mindset to the advancing new culture of science. Several social reformers in India played lead roles, and we will describe one in the next chapter, if only to illustrate the conflicts that arise whenever new ideas are trying to replace the old ones.

7. The Relevance of Raja Rammohun Roy

No account of India's development to modern times would be complete without a mention of Raja Rammohun Roy, an aristocrat from Bengal whose social reforms in the eighteenth and nineteenth centuries contributed towards narrowing the gap in attitude towards science and technology between India and Europe. I asked myself the following: If the raja had access to a time machine that brought him to the present century, what would he have thought about present-day India? Would he have felt happy that the reforms he had been associated with had been implemented? Or would he have found the country as much in need of his reforming crusade as it was two hundred years ago?

The Early Motivation

Raja Rammohun Roy was born in Radhanagar, Bengal, on 22 May 1772 into a prosperous Brahmin family. Thus he could have led the life of an aristocrat in a region ruled by the East India Company. (The Battle of Plassey took place fifteen years before his birth.) However, this was not to be. He travelled widely outside Bengal and learned several languages, including Sanskrit, Persian, Arabic, Hebrew and Greek, besides his native Bengali, Hindustani and English. He studied Western and Eastern culture and literature and was able to imbibe from and react to India's changing political, social" and economical scenario.

He was unceasingly critical of some of the long-held beliefs and traditions of the Hindus, including caste division and the ritual of sati. He broke with tradition in many ways, including translating the Upanishads in modern Bengali and travelling abroad. The former was dictated by his desire to communicate the real wisdom (as opposed to the rituals and superstitions) embodied in these texts to the common reader, who would not be familiar with Sanskrit. The latter was part of his fascination for Western culture and the newly emerging knowledge from there. For Europe at the time was going through the post-Newtonian era of science, and the Industrial Revolution was beginning. Roy understood that the emerging knowledge from the West could not be ignored. Hence he encouraged teaching English in schools in preference to the traditional and largely unchanged Sanskrit-based curriculum. In retrospect, one can now see that during his lifetime the gap between the East and the West widened rapidly— a disparity that Roy foresaw with great clarity.

Let me pause here to recall from chapter 4 Abdus Salam's comment that both the Taj Mahal and St. Paul's Cathedral are epitomes of excellence in architecture, one from the East and the other from the West. Both were built at approximately the same period and suggest that the two cultures had attained comparable heights in that field. However, in the years to come England had Newton and a spurt in the growth of science. The emerging science of the seventeenth and eighteenth centuries enjoyed patronage from the royals and the aristocracy. The Royal Society, the P Academic francaise and similar other organizations collectively promoted European science, but India had no corresponding patronage in the sciences, only in the liberal arts. This culture of science was beginning to make the difference between the development of India and Europe, and Roy foresaw its significance. Thus when the British wanted to start a Sanskrit college in Calcutta, Roy vehemently opposed the proposal and advocated an institution with Westernized syllabi including the sciences, history, geography and economics. He felt that our students needed to be equipped with modem knowledge to catch up with the West's rapid development. He was anxious that India should not lose out on the advances. For instance, he wrote to the British Governor General Lord Amherst the following:

The Sanskrit system of education would be best calculated to keep this country in darkness, if such had been the policy of the British legislature. But as the improvement of the native population is the object of the government, it will consequently promote a more liberal and enlightened system of instruction, embracing mathematics, natural philosophy, chemistry and anatomy with other useful sciences.

In those days, the general reaction to Western education was negative. The educated classes had to be convinced to accept Western education. Today we see an opposite view! It is generally assumed today that to get on in this world, education in an English medium school is essential. Indeed, so far as our urban areas are concerned, some local languages feel threatened by this invasion of English.

This is not to say that Roy was a blind follower of the West and denigrator of the East. On many occasions he had staunchly defended Hinduism against unreasonable attacks by Christian missionaries. To argue with them on equal terms, he learnt Hebrew and Greek so that he could speak with authority born of knowledge. He was deeply appreciative of the liberal philosophical traditions of India, and he founded the Brahmo Samaj, a religious movement, to popularize these enlightened ideas. When he went to England in 1830 on behalf of the titular emperor of Delhi, his lectures and discussions spread the image of India as a land of wisdom. His untimely death in England on 27 September 1833 robbed India of his leadership towards modernity.

Being Ahead of Their Times

Visionaries who want to effect social reforms encounter difficulties because of the many subjective elements that enter into the arguments for and against reforms. There are many contentious social and philosophical issues on which contemporary ideas and beliefs are unable to shed a clear light. Only in hindsight can one judge these arguments. Can scientists, with their claims of objectivity, settle these debates relatively easily? They should, but rarely can they!

I would like to give a few examples before returning to Roy. Let us recall Aryabhata with his heretical views. In the fifth century Indian intellectuals were convinced of the truth of the geocentric theory, which originated in Greece. The dogma had it that the earth is fixed and that the whole cosmos revolves around it. The Indian astronomer Aryabhata thought otherwise:

Anulomagatirnausthah pashyatyachalam vilomagam yadvat
Achalani bhani tadvat samapashchimagani Lankayam
—*Aryabhatiya* 4.9

In this shloka he gives the analogy of a person going on a boat who sees fixed objects on the land going in the direction opposite to his, and he argues that the fixed stars likewise appear to go westwards because they are viewed from the moving surface of the earth. Here Aryabhata is pointing to the spin of the earth around its axis from west to east, which gives rise to the apparent motion of the stars in the reverse direction.

The analogy is exact and clear. Yet this statement from a respected teacher and scholar like Aryabhata was ignored by his contemporaries and even by later astronomers because the statement did not fit into the overall set of contemporary beliefs. Ten centuries later, Copernicus said the same thing, stating further that the earth also goes round the Sun. His book was banned from circulation. History tells us that Italian philosopher Giordano Bruno (1548-1600) and Galileo Galilei also suffered for defending the Copernican ideas.

Lest you think that the twentieth century is different and that there has been progress towards objectivity, consider the case of Alfred Wegener, who in 1915 proposed the idea of continental drift. The idea arose from the finding that the land masses of the continents fit together like jigsaw pieces. Wegener argued that the upper crust (the plates) on the earth’s surface may have broken and drifted apart. Collisions of plates could have produced high mountain ranges. Thus the Himalayas would have formed by the plate of the Indian subcontinent moving into and colliding with the Asian plate. These ideas were pooh-poohed by the geophysicists of his time, and Wegener suffered neglect and ridicule. It was only around 1950, nearly two decades after his death, that the idea gained support to the extent that it is the accepted theory today.

One reason for this opposition was that theorists could not find a plausible explanation for the dynamics of continental drift. However, nature has previously presented many phenomena for which there were no established theories. Do we reject the reality of a phenomenon just because we can't understand it? Scientists follow the dictum 'Do not trust a theory if there are no observations to support it.' This sounds reasonable. Yet here and on many other occasions we encounter the opposite thought, 'Do not trust an observation if there is no theory to understand it.'

Confrontation between the East and the West

Like Aryabhata, Bruno, Galileo and Wegener, Roy had ideas and a vision not conforming to those of his times. So the question naturally arises as to how his ideas would have fared in the present century. Would the twentieth century have caught up with him? Before coming to specifics of Roy's ideas, let us consider how the end of the twentieth century differs from the period of his times.

If one compares the states of human existence at the ends of successive centuries, one would find that maximum change has taken place between the nineteenth and the twentieth centuries. Thanks to the scientific revolution, the human lifestyle has changed dramatically. I recall once hearing the science fiction writer Ray Bradbury make the point that the life of a human being who had lived through most of the twentieth century was science fiction converted to fact. For people who grew up in the 1920s, the notions of jet and supersonic air travel, cellular phones, lunar and planetary spacecrafts, computer-controlled automation, television, nuclear power, electronic mail, and web surfing, all would have appeared science fiction attaining reality during their lifespan. Naturally, therefore, the contrast between Roy's period and the present times is extreme.

I therefore wonder what the raja's reactions would be to the country's current state of affairs. Would he have approved the general acceptance that Western-style education has received in India? Probably so. But he would have been surprised at the growing popularity of English as a dominant language, especially now that we are no longer governed by the British. With his highly patriotic nature, he would have deplored the fact that the native Indian languages are feeling threatened. I think he would have campaigned for the Indian languages and cultures in all their diversity. At the same time, being accustomed to thinking beyond the national boundaries—a characteristic that was indeed remarkable when seen in the general ambience of his times—he would also have strongly advocated the need to learn English as the global language.

Opposition to the Sati Movement

Roy campaigned vigorously against the then prevailing and long traditional custom of sati. Sati describes a virtuous and saintly woman, but it came to be identified with a specific act of such a woman, namely voluntarily burning herself on the funeral pyre of her dead husband to show her total dedication to him. There have been legends of women carrying out this act of self-sacrifice. In reality it became a custom of subtly getting rid of widows, and far from being voluntary, it became mandatory- If a widow did not submit to this cruel act, she faced a life of humiliation, neglect, even torture.

Roy had, in general, been a campaigner for the betterment of women's lives, and his fight against sati was a natural culmination of his campaign against traditionalists. Here one is reminded of Galileo's drive against the Aristotelians, whose thoughts on nature and science dominated Europe. To project his arguments in the right context, Galileo wrote Dialogue concerning *the Two Chief World Systems—Ptolemaic and Copernican.* In this book there are three characters, of which one is a traditionalist who blindly follows Aristotle and the geocentric world system advocated by him and elaborated upon by Claudius Ptolemy. He has to defend the traditional ideas against the second character, a follower of the heliocentric world system of Nicolaus Copernicus. A third character plays a neutral role of an observer in the dialogue. Through these arguments Galileo clearly demonstrates that the traditional thinking was all based on wrong and illogical grounds.

In 1818 Roy published a tract in the form of a dialogue between an advocate of the traditional customs and an opponent. Written in Bengali, it was circulated free of charge. (He knew that his compatriots would not spend money on a pamphlet that criticized their traditional beliefs!) It was also translated into English as The Conference *between an Advocate for and an Opponent of the Practice of Burning Widows.* He published a second tract in 1820, A *Second Conference.* As in Galileo's pamphlet, both sides of the argument were presented, and the readers were left to form their own conclusions.

Let's consider one example. The Advocate asserted that sati was performed for gratification in this world and the next as it guaranteed a place in Heaven for thirty-five million years! The Opponent put forth the counterargument that performing a meritorious act with a motive for personal gain robs it of all its merit, citing as support a quotation from the *Kathopanishad:*

Faith in God which leads to absorption, is one thing and rites which have future fruition for their object, another. Each of these producing different consequences, holds out to man inducements to follow it. The man who of these two chooses faith is blessed; and, who for the sake of reward, practices rites, is dashed away from the enjoyment of eternal beatitude.

In his general arguments in support of better treatment of women, the raja argued that they had been denied normal decency, let alone given privileges, and that despite these disadvantages, they had acted with courage and magnanimity. His arguments not only highlighted the need for a sense of justice for women but also showed their strengths against the weaknesses of men. The logic of his arguments greatly appealed to the educated, younger generation.

Despite his strong advocacy for its abolishment in the face of great social opposition, the raja was unhappy when sati was banned by an act of the British government, for he believed in bringing about the desired change in social attitudes through arguments, persuasion and conviction of the merit of the case rather than through legislation. In this context, how would he have reacted to the present scenario of dowry deaths?

Although we claim to have a more enlightened society today, compared to two centuries ago, certain mental attitudes have not changed despite legislation. Even amongst the so-called educated families, the birth of a girl is greeted at best with subdued pleasure, certainly not comparable to the euphoria greeting the arrival of a boy. The treatment of the two in a family can be uneven not only in the planning for their education but also in day-to-day interaction. A bright girl, with all her merit in school, will not be given encouragement to attain her full potential, but the parents will try to go to great lengths to provide as strong an opportunity as possible for their son. There are exceptions to this scenario, of course, but 1 think nobody will question the existence of a general imbalance between the treatment of sexes in our society, which begins even before birth nowadays because unscrupulous medical practitioners will help identify a female foetus and destroy it.

Nothing, however, can compare in cruelty with the act of bride burning, as it has come to be called. Legislation exists banning dowry, and certainly for taking human life. Whereas we may point an accusing finger at the tradition-ridden society of Roy's time for burning widows, what can we say of our contemporary society, which by its inertia condones today's dowry deaths? Legislation apart, as pointed out by Roy, social awareness of the evil is more important.

Religious Reforms

Rammohun Roy was a social reformer, and his concern for better treatment of women was part of his general concern for a liberal attitude, humanism and an enlightened way of looking at life brought about by the dawn of the age of science and technology. Since religion played a dominant role in the public life of his times, he went on to reform religion itself. In 1823 he had this to say about the then current Hindu religion:

I regret to say, that the present system of religion adhered to by the Hindus is not well calculated to promote their political interest. The distinctions of castes introducing innumerable divisions and subdivisions among them has entirely deprived them of patriotic feeling, and the multitude of religious rites and ceremonies and the laws of purification have totally disqualified them from undertaking any difficult enterprise. It is, I think, necessary that some change should take place in their religion at least for the sake of their political advantage and social comfort.

The Brahmo Samaj was meant to present a reformed and enlightened version of the Vedic Hindu religion. The songs sung at its prayer meetings praised a universal god who resided as a friend and a guide in the heart of the devotee. The movement was against idolatry and recognized only one God or Supreme Being. It admitted members irrespective of caste and creed. The basis of unification was a common philosophy of universalism practised and preached by the ancient sages. Thus, contrary to the prevailing customs which encouraged a rigid religious outlook, the raja sought to revive the liberal aspects of ancient Hinduism, to free the religion from shackles of rituals and traditions.

However, let us come to modern times. How would he have found the world today? Are we any better off than our ancestors of two centuries ago? Far from being united through the new-knowledge about nature and the universe brought by science, we seern bent on religious revivalism, no matter what religion we look at. Attitudes within different organized religions are hardening, and people of different creeds are striking confrontationist poses. The caste system has not disappeared despite its official de-recognition. Although it is considered a feature of the Hindu religion, it seems to have its influence even in other religions! For even if a person converts to another religion, the legacy of his or her caste survives in social intercourse. In fact, with the introduction of various kinds of reservations, the subtle differences amongst the various backward classes have also become more pronounced. Unfortunately what Roy wrote about the caste-ridden society of his times still applies to ours. I am sure the raja would have thrown up his hands in despair at the current situation. If science and technology have failed to bring enlightenment to even the educated, then what can we say about the vast mass of our uneducated citizenry?

Developing the Scientific Temper

A term that is current these days but which was not used in the raja's times, although he advocated it in many of his speeches and works, is *scientific temper.* Scientific temper teaches us to sift the available evidence objectively and base our actions on a rational approach. Roy was a rationalist in his advocacy of reason and freedom of thought. His criticism of the existing religion and its rigid practices and caste barriers was inspired by his desire to make religion consistent with the changing world of his times. That attitude is even more relevant today, as the influence of science and technology on our lives is increasing rapidly. Thanks to the information explosion through cellular phones, fax, electronic mail and the Internet, the isolation of the East from the West that prevailed in Roy's times is no longer operative. It is said that access t6 information brings about revolutions in thinking and living. Information is supposed to dispel ignorance. Has it happened in our country? Let's consider a few instances to show that despite these technological inputs, superstitions and misinformation continue to hold on our society their strong grip. In my centre in Pune, we have the latest in computer technology to aid our research in astronomy and astrophysics. There is electronic mail, fast access to international web sites, data links with important astronomical data centres in the world, and of course the latest astronomical software for processing observational data and theoretical computations. I was once describing these facilities to an educated lady. Suitably impressed, she asked, 'Can I get a computerized horoscope made here?' Nothing that I could say concerning the demonstrated non-science or pseudoscience that goes under the name of astrology would alter her firm belief that her life was determined by her birth chart,

Statistical studies have demonstrated that there is no correlation between matching birth charts of couples and the quality of their married life. Yet the practice of matching birth charts before arranging marriages is very common, even amongst the highly educated and sophisticated strata of our society. When there is neither a scientific reason nor even empirical evidence for the effect of planets on human lives, important decisions ranging from forming ministries to moving into a new house, buying a car or starting a new business are taken with deference to the so-called auspicious or inauspicious times.

Similarly, a new fad among our educated classes is the so-called *Vaastu Shastra* (the science of architecture). This belief purports that by taking a holistic view of life, one should integrate certain specific rules for constructing one's abode so as to ensure a happy and prosperous life. The situation of one's kitchen window and the number of steps in one's staircase are issues supposedly linked with one's health, wealth, marital success and long life. People occupying distinguished positions in the society have demolished parts of their houses to rebuild them in accordance with the rules of *Vaastu Shastra,* and in some cases public money has been spent in order to effect such alterations. But can *Vaastu Shastra* be called either architecture or science? Both the architects and the scientists reply in the negative. These rules have neither rational justification nor proof of their efficacy, but believers think that defiance could cost them their well-being.

Likewise, misinformation travels fast, not only from one corner of the country to another but also from one corner of the globe to another. A few years ago, the 'news' that Lord Ganesha was drinking milk was widely believed. I wonder what Roy with all his opposition to idol worship would have made, of this event! There was nothing remarkable—let alone supernatural—in the incident, which scientists debunked with practical demonstrations in many places. The real miracle was the way the news spread so rapidly.

Such instances tell us that as a nation we are still living in the dark ages with the same outdated ideas that the raja was fighting against. Beneath the veneer of the high-tech, the social fabric today is as hidebound as it was in his times.

Some Contemporary Issues

The benign face of British rule in India is often presented as bringing new technology originating in Europe's Industrial Revolution to India. The British brought in industries, roads, railways and telegraphs. Roy was appreciative of such benefits, although in his lifetime they were rather nebulous. However, he was very conscious of the exploitation that the British rule represented in terms of unequal trade conditions. He knew that no foreign agency enters a country purely from philanthropic considerations. The technology that the British offered and sold was accompanied by an outflow of funds from India to Britain. For example, a servant of the East India Company once admitted that the annual remittances to London on individual accounts amounted to as much as £20,00,000 per annum for several years. The debate in Roy's times was between feudal monopoly and free trade. He and his friend Dwarakanath Tagore supported free trade, since they felt that introducing free trade with the Europeans and their new technologies would vitalize the stagnant development in India. They encouraged industry to grow in Bengal's countryside. They were aware that joining hands with the colonials would open India to exploitation, but they felt that this threat would be balanced by the benefits of industrialization, which would make India a player in global markets.

This debate is echoed in the present economic debate between liberalization and free-market economy versus a state-controlled economy. I am not an economist and so will refrain from passing judgement in the present debate. But even a naive person like me can see the similarity between the issues debated then and now. Do we open the country fully for the multinationals and risk being exploited by them, or do we keep the economy under strict control? Certainly, if the raja were around today he would have an opinion, a firm one too, in this debate. I feel that he would have evoked patriotic sentiments to take on the outside challenge learn what the West has to teach and attempt to do better than what it has achieved.

Another contemporary issue in which Roy would have participated with great personal involvement is the freedom of the media. In his times the newspapers informed and also swayed opinions on contemporary issues. The exploitations by the East India Company naturally got a lot of attention. There were tussles between the authorities at Fort William and the newspaper editors. At one stage in 1799, the Governor General, Lord Wellesley, imposed censorship laws to curtail the freedom of the press. These laws included prior inspection of news and views by the government and its approval before publication.

Eventually the laws became somewhat less rigid, though a lot of regulations remained in place. Against this background James Silk Buckingham started the *Calcutta Journal,* which took cudgels on behalf of the freedom of speech. Roy shared similar views and got along well with Buckingham, although he was less confrontational. Later he brought out two papers himself, the *Sambad Kaumadi* in Bengali and *Mirat-ul-Akhbar* in Persian. He used them to air several issues of social relevance to create a national consciousness amongst all Indians, Hindus as well as Muslims. Again, we find in him a person who was ahead of his times, who saw in the press an instrument to be used to assert freedom of expression, to air views of urgent social relevance and, above all, to create a general awakening amongst the masses.

These issues continue to acquire wider connotations today as the media expand their scope. The print media, as in Roy's time, play a vital role but are being overtaken by the electronic media. To what extent will governments be able to censor information? Information is a powerful weapon that all governments would like to control, but if they seek to do so through draconian measures, people like Roy will be needed to oppose them. I suspect that as it becomes possible to transmit information through many channels and more easily, it will be much harder to erect an impervious firewall around its spread.

The many qualities for which Roy is known are as cogent today as they were in his times. This may appear surprising at first sight because our present age of science and technology is supposed to be very different from Roy's times, and so one might have thought that his ideas and perceptions are out of date today. Not so! His approaches to education, social reforms, rationalism, free trade and freedom of expression are as relevant today as they were then.

Of course, when one examines Roy's life, one notices a few self-contradictions and shortcomings. Patriots may not like his soft spot for the new conquerors of his land. While stressing the simplicity of a non-feudal environment, he himself lived like an aristocrat. While speaking against several age-old religious rituals, he could not give up some himself. While campaigning against sati, he was unhappy when a legal ban was imposed on it. Some of these attitudes may be ascribed to the environment in which he was brought up and from which he could not make a complete break. What we have to see in his life is how best the man coped with the prevailing social situation and how sincerely and incessantly he strove to change it for the better.

I recently came across the following tribute to the raja from Rabindranath Tagore:

Rammohun, alas, were you alive today! Bengal badly needs you. We are a talkative lot; teach us to work. We are proud; teach us to sacrifice ourselves. We are fickle minded; teach us to remain firm in life by dint of our character- We are blinded by the external blaze; teach us to use the light within in discriminating things and to pursue only that which brings permanent good to our country.

Tagore said this in 1884 against the backdrop of the situation at the time. More than a century later, I can think of no better tribute to that extraordinary man.

PART II

Learning to Live in the Age of Science

We now come to the present, which is sometimes called the age of science. Unlike three to four centuries ago when science was confined to its narrow band of practitioners, today society cannot ignore its existence. In the following chapters we will assess the impact of science, especially in the Indian context.

The first chapter begins with a discussion of culture of science. How did science evolve over the years in Europe and in India? One must take stock of these aspects before considering India's present difficulties in adjusting to the age of science.

We then take stock of the present status of higher education and the university system, for if the country is to advance in its scientific creativity, higher education must be placed on a strong footing. Symptoms of all not being well have been many, but the present shortage of young scientists is the most telling one. The creativity of native Indian scientists seems poor when compared to their counterparts abroad. Their lack of productivity lies partly in not working in a merit-driven infrastructure and in dissociating teaching from research.

The next two chapters discuss the scientific temper, which transcends science and is an essential part of the individual and collective mindset of the Indian society. The excessive reliance on the pseudoscience of astrology is an indicator of this sad state of affairs.

The final chapter highlights the role of the fourth estate in enlightening and informing the public, a role not taken very seriously with regard to science.

8. The Culture of Science

How can science, which is considered neutral and objective, have a culture of its own? Here I am referring to the practice of science rather than science itself. How do the practitioners of science at any given epoch view their subject, how does the society itself perceive the impact of science, and what bearing does all of it have on the ethical values of the time? That such issues carry relevance to society at large—and to intellectuals in particular even outside of the field of science—is amply demonstrated, for example by the writings of D.P. Chattopadhyaya. Distinguishing between civilization and culture, he asserted that 'civilization is what we do possess or have, and culture is what we are.'[2]

One may adapt this to the present theme by saying that technological achievement is a content of civilization and the spirit that drives science is part of culture. For example, should science be harnessed for making deadly weapons that will effectively eliminate the human race? Is cloning ethical? To what extent is there an intellectual property right on sponsored research if it can be harnessed for human welfare? To put such issues in perspective, let's view them in context through a brief historical survey.

Europe c. A.D. 1050-1650

As we discussed in the case of the sightings of the Crab Nebula in A.D. 1054, the lack of records of the event by observers in Europe might have been because the study of nature took place strictly within a religious framework. Thus five to six centuries later Copernicus and Galileo encountered great hostility when they sought to cast doubts on the geocentric theory backed by religion.

Take the case of Galileo's telescope. Although tiny compared to its modern versions, this pioneering instrument led to such important findings as sunspots, lunar craters and Jupiter's four nearer satellites. Yet the intelligentsia of Galileo's time did not take kindly to the telescope, for its findings questioned their deeply ingrained beliefs. If God created the universe in total perfection, how come the Moon has pockmarks and the shining Sun has dark spots? And if the whole universe is supposed to revolve around the earth, how come Jupiter has four moons going around it? No wonder the telescope was dubbed an instrument of magic and witchcraft.

Copernicus published his magnum opus while on his deathbed. It is now widely believed that the preface is not what Copernicus himself would have written because it seeks to present the new heliocentric theory, which was the lifetime's work of the author, as an alternative hypothesis rather than as a fact—as if the writer of the preface was anticipating violent criticism of the main text of the book. It is very likely that the editor or the publisher substituted this preface in place of the author's possibly more forthright one.

Although Galileo was a staunch supporter of the heliocentric theory, he openly attacked the Aristotelian philosophy of nature. His book, *Dialogue* concerning the *Two* Chief *World* Systems— *Ptolemaic and* Copernican, heaped ridicule on the Aristotelian ideas of motion, force and so forth. While debates were not uncommon in those times, the normal practice was to confine them to philosophical arguments rather than to practical demonstrations. Galileo, perhaps the first scholar to rely on experiments to confirm or disprove a theory, demonstrated through cleverly conceived experiments how a good many of the long held beliefs were untenable.

Sensing a threat to its doctrines, the Roman Catholic Church summoned Galileo before an inquisition. Although he finally publicly recanted and accepted the views of the Church, it is said that he continued to believe in the heliocentric theory. It was not until some 350 years later, when Pope John Paul II had reviewed the historical papers relating to Galileo's persecution, that the Church acknowledged that Galileo had been right and treated unfairly.'

Thus the period from 1050 to 1650 illustrates how science in Europe was perceived as part of the tenets of the Church. It began to have an independent existence only with the advent of the Newtonian laws of motion, gravitation, optics and so forth.

India c, A.D. 450-1150

From A.D. 450 to 1150 may be considered the golden age of Indian astronomy, spanning as it does the times from Aryabhata to Bhaskara II. In the *Aryabhatiya,* the author asserts that the earth spins against a background of distant stars.[4] Contemporary astronomers commented upon this statement, but none supported it.[5] Rather they attempted to reinterpret or wish it away as something of an embarrassment.

Unlike the cases of Copernicus and Galileo, biographical details about Aryabhata are sadly lacking. How was his statement received in the contemporary circles? Was there any religious dogma that favoured geocentrism? So far as I know, the prevailing religions of the day in India had no such specific bias. The geocentric theory may have come from Greece and may have had a certain level of respectability. But this does not explain the cool reception accorded to Aryabhata. He was born in the present state of Bihar. Why did he go to Gujarat and then to Kerala, as some versions of his life story have it? Was it because of local ridicule for making a statement that did not agree with the wisdom of the day? The difficulty of answering these questions is typical of the kind chat historians of science in India face, namely, a lack of reliable documentary material.

Compared to China, Europe and the Middle East, our historical records of scientific work done in this part of the world are scanty, notwithstanding the works of the astronomers and mathematicians of this era. This dearth suggests something about the contemporary regard for these subjects. Did science as a means of understanding nature not enjoy a privileged status? Was recording data and interpreting its underlying pattern not part of scholastic studies.' I sense that in earlier times the study of science as natural philosophy was not considered a very respectable pursuit. This may well be the reason why science did not flourish in India in the next millennium until it was essentially imposed, in its by then well-developed European form, by our colonial rulers.

The British cosmologist Hermann Bondi (b. 1919) has commented thus on the success of a scientific theory: It is 100 per cent successful if it is tested and accepted, 50 per cent if it is violently resisted and rejected, and 0 per cent if it is ignored. Much though one may condemn the treatment meted out to Galileo, he at least achieved a 50 per cent success on Bondi's scale, whereas Aryabhata scored 0 per cent. Unlike Galileo who stirred up a hornet's nest with his ideas and experiments, Aryabhata does not seem to have created any impact, barring a few light ripples amongst a select few astronomers like Brahmagupta.

Post-Newtonian to Modern Times

With the success of Newtonian framework in Europe, science broke free from the shackles of religion, and a materialist and empirical approach came in its place. The hard sciences and technology were linked to cosmology and metaphysics through the various branches of science, the humanities and the fine arts. The culture of science has changed as the subject has advanced dramatically during the nineteenth and the twentieth centuries. Indeed by its strong connections to high technology, defence and the consumer world as well as to big budgets for frontier research, the culture of science has been radically transformed. In place of Isaac Newton who could afford to wait for two decades before fully satisfying himself on the viability of the law of gravitation before publishing his findings, today's scientists are guided by priorities dictated by the rush to the press even before they have completed their lab work. Or they may be forced to keep them suppressed for reasons of security or patent protection.

The relaxed style of science continued almost up to the World War II. The path-breaking—and nucleus-breaking—findings of Ernest Rutherford (1871-1937) did not require expensive machinery. Skilled and imaginative workmanship and a good lab-cum-workshop were adequate to provide all the equipment needed by scientists. The pattern changed after the war, and organized science with increasingly bigger budgets and a highly competitive spirit became the order of the day.

I shall not dwell at length on the current issues relating to organized science, weapons research, cloning and genetic engineering and the question of intellectual property rights versus the free exchange of information between scientists, although these issues have to be faced. As it would be unfair to single out professional scientists as targets of criticism since these issues deeply concern society at large, I shall focus on one aspect of growing concern that has changed our scientific culture—money. Big budgets have become a rather disturbing feature that is assuming greater significance even in the relatively calm waters of a pure science like astronomy. They have changed the culture of pure research today.

Today most frontier research costs a lot of money. (The original apparatus used by Rutherford to split the nucleus cost no more than £100.) Today's high-energy particle accelerators cost several billion dollars. In place of Galileo's one-inch telescope, which he made in his workshop, today's space telescope is a billion dollar, multi-institutional and multi-agency project. Moreover, any scientific experiment using such an expensive facility necessarily costs big money. To secure funds for this research one must approach a funding agency, usually a governmental organization. The funding agency allocates funds on recommendations of peer review committees. These committees guided no doubt by the need to allocate scarce funds in an optimum way, look for impeccable credentials of the proposer and evaluate the credibility of the proposal. As a result of this scrutiny only the safe—that is, no-risk—proposals are selected- Safety is of course decided by the criterion that what 'is to be looked for should be consistent with what we already know. While all this seems like common sense, try to apply this review process to Galileo and Copernicus. If you were a member of a peer review committee set up by the Church of Rome, you would have no option but to reject their proposals!

That we have turned full circle from those days was illustrated by the recent episode of the American astronomer Halton Christian 'Chip' Arp. Arp is a distinguished observational astronomer trained by Edwin Hubble, the astronomer credited with the discovery of the expansion of the universe and whose theory, Hubble's law, forms the basis of modern cosmology. Arp himself has many discoveries to his credit, and his Atlas *of Peculiar Galaxies is* a standard for all modern observers. Yet since the 1970s Arp has been finding several cases of galaxies and quasars that do not fit into the Hubble expansion picture. These are known as anomalous observations. The establishment's reaction to this evidence ranges from disbelief and anger to apathy, for to face these observations squarely would involve questioning or at least seriously modifying an existing paradigm in cosmology. So in the early 1980s the leading observatories began closing their domes to Arp because his observations do not fit into the existing paradigm! Nor do research journals take kindly to publishing Arp's findings. Scientists at international conferences refuse to debate the issues his work raises.

Like the medieval monks who would not record sightings of the Crab supernova because the events did not conform to their models, many modern scientists will not consider Arp's inexplicable findings. Rather they wish that these findings would eventually go away. The message from the scientific community, therefore, is that to succeed in science you must learn to conform. In such an environment how can new ideas prosper? This is the serious crisis faced by the current culture of science.

We now leave these general issues and consider the specific situation in India. Since the nurturing of the need of science occurs in higher education, we will take a look at the Indian university system next.

9. The Importance of a University

I heard following story from my father, who got it from one of the many versions of the *Ramayana.*

After Rama had returned from Lanka and begun ruling in Ayodhya, a hideous-looking dog appeared in his court, asking for justice. In Ramarajya (Rama's kingdom), even animals, let alone humans, were entitled to justice. So the dog was given a hearing, the accused being a Sanyasi (a person who has renounced the world and who lives on alms collected from house to house).

'Sire, I was merely following this Sanyasi when he suddenly beat me with a stick for no rhyme or reason,' said the dog. 'I demand justice.'

'What is your side of the story?' Rama asked the Sanyasi.

'O Rama! This dog did follow me everywhere as I went from house to house begging for alms. But everywhere the householder took a look at the dog and shut the door in fear or disgust.'

The courtiers nodded in agreement. The dog did look ugly, dirty and ferocious. The Sanyasi continued.

'Sire, at the end of the morning my bowl was still empty, thanks to this animal. I was naturally hungry and angry and took my frustration out on him.'

The dog replied, 'O Rama, I was following him so that I may also get some food. Is it my fault that he should beat me? I was born this way and cannot help my appearance.'

'Do you have anything to say, O Sanyasi?' Rama asked.

'No, Sire! The dog is right. Whatever the provocation, I, a Sanyasi, should not have lost my temper, certainly not on a dog who was blameless. I am ready for whatever punishment that is my due,' the Sanyasi replied.

'Well, let the plaintiff recommend the punishment,' said Rama as he passed on the responsibility to the dog.

The dog pondered a bit and then replied, 'Sire, seeing that the Sanyasi is a scholar, I suggest that you start a new *vidyapeeth* (university) and make him its *kulapati* (vice chancellor).'

'But that is an honour, not a punishment,' Rama exclaimed.

'Honour, yes, but punishment as well,' replied the dog. 'For, managing a *vidyapeeth* is a very onerous task. He will certainly suffer enough anguish.'

The VC's Lot Isn't a Happy One!

Whatever the authenticity of the tale, the vice chancellor (VC) of any Indian university today will agree with the bottom line. The VC's lot in this country of ours is not a happy one. He is faced with dhamas (sit-ins) and gheraos (protests) by angry students, has to mediate internecine quarrels among the faculty, is under attack from members of the university bodies, held responsible for any breach of law or etiquette, and on top of it all he is subject to subtle and not so subtle pressures from government bureaucrats and influential politicians. He has to worry about the academic timetable of lectures and examinations not getting derailed, is threatened with morchas (strikes) by employees of various categories and even has to cope with crime, drug addiction and goonda-ism on the campus. No wonder a VC either compromises his integrity in order to survive or quits in disgust. In rare cases the VC successfully combats all these problems and even surmounts them, but often at the expense of his health!

As one familiar with all three kinds, I feel that our universities have reduced the VC's post to a punishment post for any scholar of distinction and integrity. Is this the only way a university can function? Is there not a better model?

A university is much more than an institution that conducts instruction or examination of students in all or many of the more important branches of learning that confers degrees. The mere act of managing a large body of educated people in any organization is not easy even at the best of times. As with any grouping of a large number of intellectuals with different views and a natural tendency to argue, controversies are inevitable. Comparisons between individuals and jealousies in career advancement are characteristic of human nature and are unavoidable even in a body of scholars and intellectuals-Students, on the other hand, consider themselves grown-ups and no longer subject to school-level discipline, and they resent too much of authority. In short, it is unrealistic to assume even in the most idealistic case that there will be no human relations problems.

Stress on Merit and Excellence

Knowing these problems and granting their existence, is a well-run university at all possible? The answer is yes—but under certain stipulations. To understand what these conditions might be, let us look at a few well-run universities abroad. Very few universities can match Oxford's and Cambridge's traditions that span seven centuries. Yet Cambridge was established by a group of dissatisfied scholars who migrated from Oxford because of internal feuds and fights with the townspeople. Nevertheless, a positive consequence was the breaking up of Oxford's intellectual monopoly. Since then Cambridge and Oxford have maintained a healthy competition in not only academics but also sports, religion and politics. This competition has helped raise their standards in all these fields. There are traditional differences also. Oxford has produced more scholars in the liberal arts and more politicians, while Cambridge has excelled in mathematics and the sciences.

Competition is a feature that can raise the overall standard. Without it, complacency sets in. In the United States, the market economy extends to the academic sphere as well, with universities with hefty endowments vying for excellent faculty members and bright students. In the Indian setting this spirit of competition is lacking since its motivator—the desire for excellence itself—is missing. In fact, very often we suspect that our academic institutions are uncomfortable with excellence. They are happy with mediocrity since then not much is expected from anybody and everyone can bask in masterly inactivity.

The remedy is of course clear but unpalatable, if not impractical, to implement: Reward excellence and honour merit. These criteria must be applied uncompromisingly to students at their intake and their periodic examinations and also to the faculty at recruitment and its periodic reviews. That the remedy is distasteful is evident from the resistance that is immediately put up by pressure groups (representing mediocrity) to any merit-based selection or review. Strong political will is needed to counter the morchas, dharnas and gheraos that will erupt if such a policy is implemented.

Teaching and Research

A university is more than a glorified extension of a school whose sole aim consists of turning out human products stamped with degrees. No less important than teaching is doing research. Unless the teaching faculty is involved with research as well, the system will become stale and sterile. Research brings in fresh air from outside and revitalizes the teaching. As an undergraduate at Cambridge, I recall encountering new questions in the mathematics tripos papers, questions (I later discovered) that arose out of research work of the examiners.

The heights to which research can take the examination system is illustrated by this apocryphal anecdote of Lord Kelvin, the famous physicist of the nineteenth century. When he was a student for the tripos at Cambridge, William Thomson (as Lord Kelvin was called earlier) was known to be a bright student. In the final examination, however, he stood second; the first rank went to his rival named Stephen Parkinson. The examiner noted that both had solved one very difficult problem in a particular paper that had baffled all other students and that their solutions were very similar. Suspecting copying of one by the other, he interviewed both the students. Parkinson replied, 'Sir, I read research publications, and I saw a paper by an anonymous author wherein this problem was solved. So 1 knew the solution.' The examiner was impressed and complimented Parkinson for reading research papers and not limiting his attention to the prescribed texts. Suspecting more strongly now that Thomson may have copied Parkinson, he asked Thomson for an explanation. He replied, 'Sir, I wrote that anonymous paper.'

In fact, teaching and research go hand in hand, each providing fresh incentives to the other. Yet in India, sadly, the research element is greatly underemphasized in our universities, and teaching is neglected in our research institutes. Consequently, university students miss the excitement of witnessing new discoveries while the research staff in the institutes find very few-students motivated to work in their fields. In successful universities abroad, a judicious mixture of teaching and research has shown to be effective for both teachers and students. Distinguished scholars, scientists and authors on university faculties routinely give lectures to students who find the experience inspiring. Promotion criteria in our universities and research institutes should include such a mixture as an essential component for judging faculty members. Students can provide feedback on teaching, and the peer reviews can be used to assess research.

The Role of Students

An ideal university recognizes that students are adults and wish to be treated as such. Thus, while discipline has to be maintained at all costs, it should not be regimented but achieved through voluntary and responsible responses. In particular, it is fruitless to achieve or expect responsible behaviour from students if the faculty itself behaves irresponsibly. Faculty set poor examples by bunking lecturing duties, producing inferior or no research, internal politicking through groupism, submitting to external political pressure and indulging in corrupt practices. Why should students remain immune from what they see?

The other aspect of student indiscipline may arise from the dictum 'An idle man's mind is a devil's workshop.' Even if students devote considerable time to sincere studies, they face the problem of filling up their free time. They can use their time profitably by pursuing artistic hobbies, games and social work, and universities can provide opportunities for them to do this communally. Cambridge, for example, has more than a hundred clubs to fulfil different interests. There are academic clubs that highlight the recreational, historical and challenging developments in various academic fields. There are societies for cyclists, hikers and even roof climbers for outdoor hobbyists. There are debating societies; the Oxford and Cambridge Unions have produced hundreds of parliamentarians, including Cabinet ministers. Can we not open similar outlets to our students whose energies otherwise erupt in morchas, dharnas and gheraos?

In our ancient traditions in education, we find that in the gurukul system the pupils stayed with the teacher and became part of his household. Usually these gurus were sages living in forests, away from the pressures of urban life. The present notion of a university campus attempts in a way to emulate that pattern. The campus is supposed to provide a sheltered life both to the teacher and the student. But the comparison ends there. In the olden times, if the rishis found unsavoury elements such as demons or wild beasts disturbing the pastoral calm of the ashrams, they would go to the ruler to demand protection as a right. The king would honour his commitment and ensure that peace was restored and maintained. Apart from this, the sages did not go to the king but would wait for him to approach them for advice or assistance.

Can our rulers today claim that they also do not interfere in the life of a university campus? Likewise, can our university intellectuals claim that they remain aloof from aspirations of power to be obtained from the rulers? Today's Sandipani, Vyasa or Valmiki would like to be on various power-wielding committees for which they would need political patronage. Similarly, instead of removing unsavoury elements from the campus, our political parties add to them.

In the last analysis, the success of a university depends not so much on funds, living conditions or the cost of living but on the mindset of the teachers, students, government and society at large. Even in the pre-lndependence days of austerity with a hostile government, Mahamana Madan Mohan Malaviyaji could make Banaras Hindu University (BHU) a truly national institution with dedicated teachers and motivated students. Where does BHU stand today? It is a prestigious central university, financially much better off than in Mahamana's time. But can it claim to possess the same high academic ambience today as it did sixty years ago' To understand this transformation, we need to ask ourselves these questions: What attributes does a good university need to acquire and what does it need to avoid'

The Numbers Game

The present century dawned when India was still shackled to imperialistic rule with no immediate possibility of living as a free nation or ability to chart its own policies. At Independence there were high expectations in every field. We lived more than half of the twentieth century as a free nation. Naturally there has been and will be considerable brainstorming on whether pre-Independence aspirations have been fulfilled. Indeed, one may even ask if, while taking a forward step in some aspects of higher education, we have also taken two backward steps in others.

I shall deal here only with some aspects of higher education and outline a few outstanding problems, some inherited from the British and some of our own creation. Let us take the case of the universities which present a mixed picture today. The number of universities and students securing university education, the variety of courses offered and the support for expensive equipment have all gone up enormously since Independence. As a matter of fact, one is constantly presented with such reassuring statistics. Yet there is an underlying feeling that this growth has been achieved at the expense of quality.

Although the number of universities today is four times the number before 1947, how does a typical university today compare with a pre-Independence university in terms of the calibre of its teachers, students, examinations or even the quality of its buildings—in short, quality per se? Compare any old university like Kolkata, Mumbai, Allahabad or Banaras with what it was fifty years ago. You would have to be blind not to see the sharp decline in quality at all levels.

The reasons are many and have been discussed in several fora ad nauseam. They can be summarized thus: First, there is continuous external interference in the day-to-day running of a university with the result that it cannot enjoy autonomy even if it wants to. Second, exercise of autonomy requires the strength of conviction and the courage to push forward the right policy. Today neither the authorities in university administration nor the academic faculty are in a position to operate independently. One reason for this is that intrinsic merit—the backbone of courage and conviction—is lacking. The appointments of vice chancellors are often politically motivated rather than made on academic grounds. The reservations policy, a parochial son-of-the-soil syndrome and administrative inertia have contributed to a decline in academic quality. Third, the view that universities must only teach and that research is secondary has deprived them of a lively and fresh academic atmosphere that comes only when teaching and research go hand in hand. The growth of the culture of autonomous research institutes and national laboratories has shifted research activity largely out of the ambit of the university. Fourth, politicking amongst faculty members and the obvious weakening of the merit criterion for recruitment and advancement have resulted in a general decline of discipline and academic values in the student body.

It is often asked with nostalgia, why do we no longer have distinguished scientists, teachers and scholars, the likes of which used to thrive in the pre-Independence universities? Where are the intellectual giants that used to lead universities as vice chancellors, to whom the politicians would listen with respect rather than issue orders?

A Decline in Quality

It is estimated that only 7 per cent of the applicable population receives higher education. If this percentage is maintained, there will be some 11.7 million students receiving higher education by the year 2008. If the percentage is increased in stages to 10 per cent, the number will rise to a staggering 12.9 million. Although this is a huge number of university students, percentage-wise (in regard to population) it is not that large.

Nevertheless, these large numbers are mainly responsible for the decline in quality. We must ask why students are opting for particular courses. Is it because they are academically motivated to pursue a certain subject? Is it because the course is essential for the job market? Or is it because there is no other avenue open for 'value addition'? (Like a consumer product passing through a factory, the individual is supposed to acquire added value through education.)

Most students pursue higher education to get degrees to be used as passports for seeking jobs. Yet there is a large, highly educated but unemployed youth force, which clearly indicates a mismatch of supply and demand. The word *university* comes from the same root as *universe,* that which encompasses everything. Consequently, the presumption is that a university should provide all kinds of educational programmes. Has the universality been properly used b> the universities to adapt to the changing social needs of the country? Universities should introduce vocational programmes to enable students to secure a useful livelihood, but society has to recognize those new courses as respectable and suitable. For example, a clerk's post today may require familiarity with computers and a good command over the relevant computer language. A .conventional degree does not guarantee either. Yet, ironically, the degree is held compulsory whereas a diploma that ensures these attributes is often not recognized by employers.

The government of India—the largest employer in the country—can bring about a change of attitudes by setting the trend. The pressure on conventional university courses can be considerably reduced by diverting students to non-conventional courses after an aptitude test. Students who have no motivation towards a conventional degree course and are studying it by default, as it were, would greatly benefit by the opening of additional channels that have the added stamp of respectability from a university.

The Issue of Reservations

At the Inter-University Centre for Astronomy and Astrophysics' computer centre we once advertised for a reserved post in systems management. We received very few applications—a common enough occurrence. As none of the candidates was even remotely suitable, we considered advertising the post again. Then somebody pointed out that a very competent young man appointed to a temporary project in the centre was eligible to apply but had not done so. When asked, he said that he knew about the opening and that he qualified for the job, but as the post was reserved, he felt his selection would not be seen as proof of his merit. Thus he did not want to get into a post that was reserved and where the criteria for selection were invariably relaxed. Instead he wanted to compete for an open post where his mettle would be seriously tested.

This episode underscores the fallacy and failure of the present system of reservations. The system was originally introduced with the noble intention of affirmative action towards the backward classes. Indeed, affirmative action policies like this exist in advanced countries as well. In India, however, the policy has been singularly unsuccessful in righting the wrongs and eliminating the gap between the haves and the have-nots in society. Ironically, politicization of the issue has only succeeded in widening the gap.

In my opinion, the best way of narrowing and sealing this gap is through education, not just at the primary level but at the higher levels as well. If affirmative action had concentrated in special training programmes for the backward classes, with special provisions for scholarship and stipends to encourage those doing well, by now we would have had a sizeable, proficient pool from this group. Such persons would have competed for open posts and got in on merit, instead of" under the stigma of a reserved post.

Indeed, the creation of reserved posts has bolstered the impression that those getting in through this stream are less qualified and cannot make it through open competition. Nothing can be more degrading to the human mind than such a patronizing view. Yet this system not only persists but continues with the government's encouragement.

The devastating impact of the reservation policy on higher education over the years is all too apparent. Posts from lecturers to professors remain unfilled for lack of suitable candidates or, worse, they are filled willy-nilly under the government directive to fill up the quota within the prescribed deadline, thereby forcing a serious compromise with quality and merit. Imagine the national cricket team sent out to play international matches with five out of eleven players chosen compulsorily from the reserved category. If the performance of the team is below par, who should take responsibility? Fortunately, we have not yet reached this stage because the competitive state of the game requires that we send in our best players. Why should the same criterion of competitiveness not be applied to our universities and colleges of higher education, which also have to be judged by an international yardstick?

Merit and Funding

In addition to quality and equality, financial support is a major issue in higher education. The main funding body for our universities, the University Grants Commission (UGC), faces two problems: how to dish out the meagre funds granted by the government for higher education to a large number of claimants and how to guarantee that its funds are properly used. The first problem arises because the UGC tries to be democratic in its approach: if it were not, it would invite tremendous criticism and allegations of favouritism from all quarters. The second problem comes from the autonomy claimed by the universities in managing their affairs.

In an attempt to remedy these problems, the UGC has created the National Assessment and Accreditation Council (NAAC) to evaluate and rank the performance, facilities and so on of institutions in the university sector. If the NAAC is able to do its job properly, we should know which universities are excellent and which are ordinary, which departments are reputable and which are mediocre. This evaluation will be done against the backdrop of national and international standards. It is too early to say if this experiment, well-motivated though it is, will succeed. It is voluntary, in the sense that an institution is not obliged to be assessed. However, if the ranking is linked with grants of funds, the idea may catch on faster. This will also help the UGC decide where to invest its modest moneys. The success of the entire operation depends on transparency, political will and a clear emphasis on merit.

Another merit-driven operation might be as follows. The erstwhile Science Advisory Council to Prime Minister Rajiv Gandhi suggested a small cess on the budgets of the major science agencies (Department of Atomic Energy [DAE], Defence Research and Development Organization [DRDO], Department of Science and Technology [DST], Department of Space [DOS1 and Department of Scientific and Industrial Research [DSIR]), which in turn could be channelled towards the upliftment of universities' research and development. Funds like these provide incentives to do research, which are presently very scarce. Even a small 3 per cent cess would generate resources that could produce a sea change in higher education, provided that it is used as a reward for merit and creativity rather than as largesse to be distributed democratically.

New Technologies

We can further transform our universities by taking advantage of communication technologies. With the advent of the space programme and communications satellites, the growth of photonics and optical fibre technology and the phenomenal rise in the use of computers, the modes of communications have enormously expanded in efficacy and power. The Internet has already shown us how information transfer can proceed quickly, painlessly and relatively cheaply. Keeping these factors in mind, the following scenarios emerge for the future of higher education.

1. In an extension of the Open University system, one can have an interactive classroom where pupils, singly or in groups, in different places listen to lectures and panel discussions and view lecture demonstrations while interacting with the resource personnel.

2. In the era of shrinking library budgets and escalating prices of books and journals, networks of libraries with the electronic transfer of information can supply the needed browsing facility to students and teachers as well as the ability to access books or journals remotely.

3. Electronic mail, which is gradually replacing the conventional hard copy mail, allows two or more persons to converse via their computers, to access databases in different parts of the world, to operate telescopes remotely and so forth. By saving travel and money, it can make a future educational system much more efficient and cost-effective.

No country planning for the future of its-education can afford to ignore this potential. For a country like India with its far-flung, difficult-to-access areas, this technology will be a boon. It will indeed be a tragedy if our planners fail to cash in on it.

4. Technology provides new instruments, especially in scientific disciplines. The astronomers have their telescopes, and the nuclear and particle physicists have accelerators. In each discipline there are sophisticated facilities. Unfortunately they cost a lot, and providing an expensive facility to each university is not economically feasible.

The experience to date has not been very encouraging with expensive equipment lying underused or even inside the unopened crate. How do we solve this problem?

Even in advanced countries with greater prosperity, the shrinkage of available funds and the low-use factor have forced universities into a sharing mode. Thus many institutions share expensive pieces of equipment like telescopes or accelerators. A similar culture needs to be popularized in India. A beginning has been made by introducing inter-university centres (IUCs) in areas inadequately covered by universities. A typical IUC acts as a nodal point providing access to advanced and expensive facilities to users from various universities.

In some cases this organization has to address or circumvent a resistance from the very universities for which it is intended. They tend to see it as a diversion of funds that would otherwise have come to them. Actual demonstration of its success would be more effective than any verbal argument put forward in favour of such a mode. As such, it very much depends on the few lUCs created so far to show how effective joint use can be.

Why is higher education so relevant to science? It may be tempting to consider science and technology as the driving forces of society today and view the humanities and the arts as irrelevant, but this argument is short-sighted. As we shall discuss in later chapters, the science-society interaction can benefit society only if society is mature enough to look beyond the narrow confines of science. For this, higher education will become increasingly more important.

10. A Direction for Indian Science

While looking towards the future, it helps to look backwards first to see how Indian science has fared during the twentieth century. What were its top ten achievements? Could our overall performance have been better? Were any crucial decisions taken wrongly? Can we use past and present trends to plan for the future?

Top Ten Achievements of the Century

In a roughly chronological order, here are what I see as highlights of Indian science in the twentieth century:

1. Srinivasa Ramanujan, discovered by the Cambridge mathematician G.H. Hardy, whose great mathematical findings were beginning to be appreciated from 1915 to 1919. His achievements were to be fully understood much later, well after his untimely death in 1920. For example, his work on highly composite numbers (numbers with a large number of factors) started a whole new line of investigations in the theory of such numbers.

2. Meghnad Saha’s ionization equation (c. 1920), which opened the door to stellar astrophysics.

3. S.N. Bose’s work on particle statistics (c. 1922), which clarified the behaviour of photons (the particles of light in an enclosure) and opened the door to new ideas on statistics of micro-systems that obey the rules of quantum theory.

4. C.V. Raman’s discovery that molecules scatter light (c. 1928), which became known as the Raman Effect. It is used to study the internal structure of molecules.

5. G.N. Ramachandran's work in biology (c. mid-1950s), for which he is considered one of the founders of the rapidly developing field of molecular biophysics.

6. The Atomic Energy Commission's development of atomic energy power and nuclear capability through a dedicated programme (founded in the 1950s).

7. The green revolution in agriculture (the 1960s and 1970s).

8. Development of space programme and satellite fabrication/ launching capability (from the late 1970s).

9. Work in the various labs on high-temperature superconductivity (since the late 1980s).

10. Progress towards transforming the Centre for Scientific and Industrial Research (CSIR) labs' orientation from workbench research to industry and the marketplace (since the late 1990s).

From this list we can see a shift since Independence from the individual scientist to organized science. Leaving aside the hype of 'third largest scientific manpower', Indian scientists have individually done well—even excelled—in their chosen fields at the international level. However, the individual achievements represented by the first four in my above list, which could be considered in the Nobel Prize class (although only one could get it), have been rare and hard to match.

It is generally argued that Indians have done better when abroad in a developed country, and the cases of Subrahmanyan Chandrasekhar and Hargobind Khurana are cited by way of examples. However, leaving aside Nobel laureates as somewhat exceptional cases, if we look at the next range of scientists, we find that native Indians are not far behind their non-resident counterparts. One way to judge this is to look at memberships of foreign academies and honorary memberships of professional societies. We find that native Indians have been so honoured and awarded in fair number. Another criterion of recognition is through the official positions at the apex bodies of the International Council of Scientific Unions with its respective member union organizations. These memberships including leadership positions are tokens of the scientific reputation of the persons concerned, and here too natives have done as well as (perhaps even better than) the non-residents.

In this day and age of recognition, citations of work in scientific publications are given importance, and here Indians have not fared well. The citation rate overall is low and also falling year by year. However, one should remember that even Europeans complain about being ignored by the Americans in citing their work. Given the economic disadvantage one starts with in the present era of high-budget science, one should view the performance figures of Indian scientists more sympathetically than is usually done.

Wrong Turnings

Nevertheless, there is no room for complacency. We could have done better, given the pool of talent and intelligence we started with at Independence, given that the first Prime Minister understood and appreciated the role of science and was willing to support its advance wholeheartedly, given the respect science enjoyed amongst the bright young students of the time. But we didn't. It is easy to pretend Co be wise after the event. After all, we realize that a wrong turning has been taken only after we go down the road some distance. So here are my answers, again with the disclaimer that, right or wrong, I am speaking only for myself. The significant step taken around the time of Independence, to increase the ambience of science in the country was to set up autonomous research institutes (ARIs) in various research areas.

The Tata Institute of Fundamental Research (TIFR) created in 1946 set the tone. The TIFR initially sent scientists for training in the West, but with the aim that subsequently the institute would become self-sufficient in this respect. This was fulfilled, and eventually the TIFR provided the intellectual material for several areas including mathematics, theoretical physics and the country's atomic energy programme. The CSIR also worked for self-reliance by creating advanced laboratories in different fields all over the country. Today we have a large network of ARIs created by the various scientific departments of the government of India, the DAE, DRDO, DST, DOS, DSIR, Department of Electronics (DOE), Department of Bio-Technology (DBT), etc.

Looks good? But here is the catch: None of these ARIs has any integrated link with any university, even if the university is in the same town. So except for their very limited research scholars, these ARIs have no exposure to the student population. Contrast this with research in several advanced countries where top-class research is carried out amidst the ambience of a university with the distinguished scientists lecturing to the undergraduates. Being lectured to by high achievers can inspire and motivate students. Even seeing the distinguished scientist on the same campus can have a salutary effect. I can speak from personal experience, having attended lecture courses by Paul Dirac and Fred Hoyle at Cambridge and having seen G.P. Thomson on the river towpath and Max Perutz chatting in a cafe.

When creating the ARIs, the primary consideration must have been to provide a hassle-free environment for dedicated research, far from the madding crowds of university dons and rowdy student masses. In actuality, it became like the Indo-Pak cricket test match at Calcutta's Eden Gardens from where all spectators were banished for rowdiness. The match continued unhindered but shorn of all fun and excitement. We are now paying a heavy price for this oversight in the early planning. For now the ARIs are finding it more and more difficult to get good research scholars and young scientists to keep the subject fresh and flourishing for the future.

By and large, students do not find a scientific career attractive any more. Medicine, engineering, computers and chartered accountancy are high among the career choices for top secondary-school students. Very few choose the sciences because they know that if they opt for a Bachelor of Science stream, there is no excitement there, no motivating teachers any more.

The Universities' Demise

Simultaneously with the creation of the ARls, the downgrading of our once excellent university system also began. As opposed co the ARls which were divorced from teaching, the successive government acts ruling universities made them more into teaching factories where the workers' hours are counted by bureaucrats each time a pay revision takes place. When merit as a criterion for selection goes out of the window, when research is no longer regarded as essential for an academic career, we have no reason or justification to demand that a university produce quality.

In the headquarters of the University Grants Commission there is proudly displayed a quotation by Jawaharlal Nehru:

A university stands for humanism, for tolerance, for reason, for the adventure of ideas and for the search of truth. It stands for onward march of the human race for still higher objectives. If the universities discharge their duties adequately, then it is well with the Nation and the People . . .

If there is a general feeling that all is not well with the nation, then we should ask ourselves if we are allowing the universities to discharge their duties adequately.

Science vs. Administration

Next let us look at the ARls, where considerable scope also exists for improvement. Take the organizational structure of their scientists. Depending on their seniority the scientists are ranked in grades labelled A to H, with the Scientist H being at the top of the ladder. It does not require a great intellectual exercise to see that these grades are exactly parallel to grades in administration with Deputy, Joint and Additional Secretaries having their counterparts in the scientific cadre.

It also does not require a great deal of imagination to see that scientific research is a different kind of activity to administration. Apart from the different mindset, expertise and modus operandi of scientists from bureaucrats, their evolutionary tracks are also different. Scientists are at their most adventurous and productive stage when young, being on the right side of thirty-five years, say. A bureaucrat, on the other hand, matures with age, gaining wisdom through experience of work. Thus whereas the most path-breaking results are obtained by the young scientists, it is the mature administrator who is called upon to take crucial policy decisions.

This difference is not reflected by the existing organizational structure and evolution of a career for a scientist vis-à-vis an administrator. What is needed is provision of fast track promotions for the high scientific achievers. Likewise, when in later life the work of a scientist slows down, his/her career advancement should likewise be slow and steady.

Unfortunately, the promotional avenues for scientists do not take note of this 'fact of life'. A highly productive young scientist with international recognition often finds himself clubbed with a mediocre colleague who hardly does any noteworthy work: Both are promoted in the same way. Similarly, at the other end, senior scientists well past their good productive phase keep advancing up the ladder described above as a matter of routine.

This merit-based movement up the ladder is essential to attract young, creative talent to science. At present the outside perception of several of our ARIs by young students is that they are manned by scientist-bureaucrats. Certainly, the A to H-type ladder tends to encourage officialdom amongst the scientific cadre analogous to that in administration. For example, a Joint Secretary may speak to and order about a Deputy Secretary, but he dare not initiate a dialogue with his superior ('speak only when spoken to!'). In science, free discussion on an emerging scientific idea between the young and the old, between the raw and the experienced, is required and should be encouraged. But this happens rarely in an AR1 because of its hierarchical structure.

Finally, our ARIs do not have a rigorous external monitoring system to ensure that high-quality work is indeed being done and that merit is acknowledged and appreciated. A distinguished ARI appointed an external review committee only in its fiftieth year—and that too when there were many problems to sort out. The review committee made sweeping recommendations, including replacing of the director, to rectify the situation!

Present Highlights

Let us briefly look at the present state of science in India. On the positive side we may cite the following:

Progress in agriculture, including the green revolution: This slowly but surely transformed the nation from having to move round with a begging bowl to worrying about how to store the reserve food grains. This is no mean achievement considering the rising population, which has nearly tripled since Independence.

Ayurveda: Thanks to the awareness of intellectual property rights, we are now waking up to our as yet sporadically explored native medicine. For instance, in 1995 the US Patent Office granted a patent to two non-resident Indians at the University Of Mississippi Medical Center in the US for the use of turmeric for healing purposes. This was challenged by the CSIR, New Delhi, on the grounds that turmeric had been used in that capacity in India for thousands of years and as such the patent lacked novelty. This case was accepted, and the patent was revoked in 1997. The example of the turmeric patent brought home to us the need to protect the ownership of our ancient knowledge, as also doing more work to extract any hidden gems beneath a whole lot of ritualistic methods.

Venture funding: The CSIR has introduced this concept to encourage new inventors with bright ideas. It is bound to yield positive results in at least a few cases. The CSIR has also encouraged closer contact between laboratories and industrial plants by requiring its laboratories to raise a considerable fraction of their funds through interactions with industry.

Biotechnology: India has responded quickly to this growing field. It set up a separate government department of biotechnology in the late 1980s and has also created laboratories and a project mechanism to promote research in this field.

Space programme: India's achievements in space with recent successes in satellite launching technology have created self-confidence that will prove valuable to greater challenges that lie ahead. Even lunar missions are now being talked about, with the inevitable discussion as to whether a poor country like India can afford such 'luxuries' of research. Not only can we afford these leaps of basic science, but we also stand to gain from them. Indian Space Research Organization's record in this respect has been excellent, its work in remote sensing and communications technology standing as just two such examples.

Although rockets, satellites and spacecrafts excite the common imagination, space technology can have its sinister side too. Missiles can also be launched with this technology, and we can put nuclear warheads in space. Can India afford them? On an even higher moral level, can a nation known for popularizing non-violence, participate in this kind of destructive technology? Clearly agonising decisions lie ahead, as one could see from the nuclear explosions at Pokhran in 1998.

Perhaps this is the stage when one could turn to the negative aspects of the present picture. The greatest worry faced by senior scientists and science managers in India today is what is termed the missing *generation.* There does not seem to be a younger batch of the next-level scientists to replace the present leaders. Normally a nation talks about a missing generation when it has participated in a devastating war. There was no such war, yet there is a singular dearth of younger scientists. Where are they? Starting in the 1980s, there has been a slow but steadily rising flow of young talent away from science and technology. Even the graduates of India's well-run and highly successful Indian Institutes of Technology (IITs) now routinely turn to management after a few years, leaving unused their proficiency in technology. Those bright ones who do not go to an IIT turn to professional courses like medicine or engineering in preference to science. And, of course, there are some who leave the shores of this country and seek careers abroad.

Thus India, which once boasted the third largest scientific manpower in the world, is finding it hard to get new scientists to replace those retiring. The situation is not irretrievably lost, for if one demonstrates that a scientific career in India has intellectual challenges coupled with a comfortable life with the minimum of red tape, it may be possible to attract our motivated youth to science. We need to create rapidly merit-based career advance schemes for young scientists, make it easy for them to take and implement decisions and also have transparency in administration. Furthermore, our universities need to be rejuvenated with research opportunities for their faculty so that it can inspire students with demonstrations of science in action.

These changes should not be seen as radical reversal of what has been done; rather they represent a midcourse correction. Given a change of environment, there is a lot of glamour left in science, one in which our students can participate. I foresee thrust areas in materials science, molecular biology, information science and technology with so many applications beneficial to society. Likewise, the basic sciences of astronomy, astrophysics and particle physics pose several challenges of the highest order to human intellect. In short, we have the talent, and we see the goals clearly. What is needed is a change of environment.

11. The Scientific Temper: An Urgent Indian Need

A few years ago I attended an international and interdisciplinary conference dealing with the issues man has to face in the twenty-first century. Naturally the global environment, population control, food availability, communications, education, and science and technology featured prominently. As speaker after speaker covered a variety of topics of great relevance to the theme of the conference, I increasingly began to feel like a diner at a sumptuous buffet searching desperately for that tiny but vital item, namely, the salt shaker. By that pinch of salt I mean the scientific temper, an essential component of man's mental framework in his struggles to face the challenges of the present and the future. Let us first look at the concept of the scientific temper in general and then examine how today's Indians, individually or in a society, stand vis-à-vis its acquisition or application.

What is scientific temper? Is it an individual trait or does it also extends to societies, cultures, civilizations? To what extent is it prevalent today? What can be done to make it more widespread? Jawaharlal Nehru described it in this way:

The impact of science and the modern world have brought a greater appreciation of facts, a more critical faculty, a weighing of evidence, a refusal to accept tradition merely because it is tradition . . . But even today it is strange how we suddenly become overwhelmed by tradition, and the critical faculties of even intelligent men cease to function . . . Only when we are politically and economically free will the mind function normally and critically.

This was written during the British Raj. Today we live in a free India that is feeling its way towards economic prosperity. Yet we are still a long way away from achieving that scientific outlook which Nehru considered so essential for our future well-being. To appreciate what the scientific outlook is all about, let us first see how science itself works.

The Scientific Method

Schoolchildren learning science are told that a scientific investigation consists of three steps: experiment (E), observation (O) and deduction (D), This particular pattern of investigation has emerged after centuries of practice, and the scientific outlook lies somewhere at the bottom of it. Science itself arose out of man's curiosity about nature—the what, the how and the why. Each answer gave rise to many more questions. While a correct answer closed one particular subject, it simultaneously opened up several new ones, and this proliferation of questions and answers progressively led to the vast and expanding field of science that we see today. Alexander, before he became Great, once complained that because of his father's conquests he would be left with no more worlds to conquer. With so many mysteries of nature to unravel, a scientist will never be in that position.

Let us see how the E-O-D process operates in science. As mentioned above, its beginning lies in some questions about nature, let us say, about a certain phenomenon in our physical world. An experiment is set up to observe the phenomenon in several different ways. The experimenter can, in many cases, alter the various operating conditions to enable him to study the outcome in as many situations as possible. He also tries to eliminate the human element as far as possible and obtain objective results. That is, the result or the outcome of the experiment should not depend on who is performing the experiment.

The result of the experiment may be qualitative or quantitative. In the latter case, the scientist ends up with a set of figures. Before any deduction can be made, it is often necessary to detect a pattern in the observed results, and this is where the so-called signal and noise come in. Here *signal* represents the pattern which one is looking for against the background of a maze of data, the noise. How does one extract the signal? An experienced experimenter is very often able to detect this. There are cases, however, of the proverbial needle-in-the-haystack type, where this is not possible and help must be sought from the statistical methods of data analysis. Recourse to statistical methods is in any case desirable to ensure objectivity. Unfortunately, there are situations where even statistical methods are not able to give unambiguous answers. The scientist then returns to the drawing board to design new and better experiments.

The last, but by no means the least, step in this process is that of deduction, i.e., drawing a conclusion from the experiment. The scientist, of course, must repeat the experiment several times to check if he gets the same result. He is also interested in making predictions for other situations not covered by his experiment— for example, for situations beyond the range of his present experimental parameters. The purpose of this exercise is to prompt future scientific experiments to be designed to test these predictions.

This interplay between theory and observations is what keeps science going. Without scientific theories to guide him, the experimenter will not know exactly what to observe. It is only when the theoretical scientist tells his experimental counterpart some of his predictions that the latter can design suitable ways of testing them. Nor can the theoretician work in isolation forever. Unless he produces scientific predictions that are testable by observations or experiments, his theories will be considered sterile.

Littered with Sterile Knowledge

The history of science is littered with sterile theories and theories which were ultimately proved to be wrong. It is necessary to make a distinction between the two types. The former types, without any observable predictions, did not contribute to the growth of science. The latter types may have been considered viable for a while and prompted experiments that eventually led to their disproof, but in this process the scientist was also able to advance his knowledge.

Indeed, the modern scientist knows that no scientific theory, howsoever right it may seem to be at present, will be entirely correct. Sooner or later some new experiment will be designed which could disprove some crucial prediction of the theory. For a while this may lead to an apparent breakdown of law and order in the regime of science, but experience has shown that an enriched order eventually emerges. Thus the scientist regards the proof of a well-established scientific theory as a very exciting event. It means that Nature has considered man mature enough to share and appreciate yet one more secret from her bag! It was in this connection that Hermann Bondi remarked:

The essential thing in science is for the scientist to think up a theory. There is no way of mechanizing this process; there is no way of breaking it down into a science factory. It always requires human imagination, and indeed in science we pay the highest respect to creativity, to originality. It is, of course, clear that since every theory must live dangerously, the casualty rate is pretty high. So we do not honour scientists for being right; it is never - given to anybody to be always right. We honour scientists for being original, for being stimulating, for having started a whole line of work. Science is the most human of endeavours because it depends on cooperation, it depends on people testing each other’s work and it depends on people taking notice of each other.[2]

However, the scientific outlook need not be the prerogative of the scientist alone. After all, it owes its origin to human curiosity about nature, and as such every one of us, whether a scientist or not, is entitled to it. Indeed, just as scientific progress can be achieved only when the scientific outlook prevails over innate conservatism, so this outlook acts as an antidote to the evils of prejudice and superstitions.

Science and Superstitions

Superstitions are born out of ignorance of how nature functions. Science is dedicated to the unravelling of the mysteries of nature. As one particular mystery *is* solved, we should expect the superstitions based on it to disappear. Yet this does not always happen in practice because of the typical human being's lack of scientific outlook. I shall illustrate with the example of a superstition that has tenaciously held the Indian psyche despite conclusive evidence to the contrary. Early human societies ascribed occult powers to planets. This assumption arose from ignorance of what planets are and how they move. Now that astronomy has answered all questions about planets raised by primitive man, we should expect this assumption to be regarded as groundless, yet this has not happened. Even in the technologically advanced countries belief in astrology persists. In the mid-1970s a group of leading scientists in the West signed a circular denouncing the very basis of this belief. It reads in part as follows:

It is simply a mistake to imagine that the forces exerted by stars and planets at the moment of birth can in any way shape our futures. Neither is it true that the position of distant heavenly bodies make certain days or periods more favourable to particular kinds of action, or that the sign under which one was born determines one's compatibility or incompatibility with other people.... In these uncertain times many long for the comfort of having guidance in making decisions. They would like to believe in a destiny predetermined by astral forces beyond their control. However, we must all face the world, and we must realize that our futures lie in ourselves, and not in the stars.

Do planets influence human destiny? How can a scientist test the hypothesis that astrology works? He will not be satisfied by the prediction by a single person based on a single horoscope. First, he will require a sec of well-defined rules on which such predictions are based. The rules should be unambiguous so that different persons make the same prediction from the same horoscope. Next, he will need to be convinced that these rules work in a statistically significant manner to discount the possibility of the prediction being right purely by chance. This will require a systematic study of a large number of such trials under different conditions.

For example, suppose someone claims to predict with reasonable accuracy whether a tossed coin will fall with heads or tails up. Will a single toss decide the truth of his claim? We all know that anyone can correctly predict the outcome with 50 per cent accuracy. How do we check if the claimant has extraordinary powers to make the prediction with a higher level of accuracy? Suppose we ask him to perform this prediction test 100 times, and he predicts correctly fifty times. Again we will argue that this is not a significant indicator of his predictive power. But suppose he is accurate fifty-one times. Do we give him credit? What if he is accurate seventy times? Where do we draw the line? The statistician comes to our rescue here by devising tests to decide whether the success achieved in a particular experiment is purely due to chance or to some other factor (for example the ability to predict correctly in the above cases or the possibility of the coin being biased).

Likewise, tests have to be made of the above hypothesis about planets. It is necessary to cast the prediction in a well-focussed form where it can be tested. Such tests as have been conducted so far by scientists have yielded negative results. But again it is not always necessary to call upon a professional scientist to perform such tests. The educated common man can sift the evidence provided he adopts an objective outlook.

Let me give two illustrative examples of experiments of this kind conducted in the United States to test the scientific predictability of astrology. In the first test, the marriage and divorce rates in Michigan in 1967 and 1968 were analysed. The sample was large—2978 marriages and 478 divorces. The birth charts of the couples involved were examined by astrologers who were asked to opine whether the horoscopes matched sufficiently to warrant the conclusion that the couple's marriage would be long-lasting and happy. The astrologers made out two lots, one with matching and the other with conflicting horoscopes; those in the former category should have a stable and happy marriage whereas those in the latter should not. These so-called predictions were then compared with the actual state of marriages of these couples. It was then a simple matter to test the argument between the actual and the predicted classifications of the sample. Rigorous statistical analyses demonstrated that there was no correlation between predictions and results.

The second test throws some light on the psychology of people who are attracted by astrological predictions despite their scientific temper.[5] This aspect is sometimes called the Barnum effect, coming from the famous Barnum and Bailey Circus in the United States. When the circus owner P.T. Barnum was asked why his circus was so popular, he explained that it contained a variety of acts of which at least one would appeal to every individual, and so people would sit through the entire performance, despite getting bored by many of the other acts. Likewise, astrologers phrase their assessment of an individual in a vague but all-pervasive form, such that at least a portion of it may be found appealing by the individual. A characterization of an individual prepared in this way is known as the Barnum Interpretation (BI). A typical BI may be stated as follows:

You have a great need for other people to like you and admire you. You have a tendency to be critical of yourself. You have a great deal of unused capacity that you have not used to your advantage. While you have some personality weaknesses, you are generally able to compensate for them. Your sexual adjustment has presented problems for you. Disciplined and self-controlled outside, you tend to be worrisome and insecure inside.

At times you have serious doubts as to whether you have made the right decision or done the right thing. You prefer a certain amount of change and variety and become dissatisfied when hemmed in by restrictions and limitations. You pride yourself on being an independent thinker and do not accept others' statements without satisfactory proof. You have found it unwise to be too frank in revealing yourself to others. At times you are extroverted, affable and sociable, while at other times you are introverted, wary and reserved. Some of your aspirations tend to be pretty unrealistic. Security is one of your major goals in life.[6]

Now this experiment involved fifty-two individuals whose birth particulars were given to noted astrologers for making up interpretations of each one's personality. Each person was then given three interpretations: (i) the one applicable to his/her birth chart, (ii) another one belonging to some other individual in the group chosen at random and (iii) the BI. All persons were then asked to rank on a scale of five how accurately each interpretation fitted their personality. Almost invariably the BI turned out to be the most popular with an average rating of 3.69 out of five. The scores of the other two interpretations hardly differed between them with interpretation (i) scoring 3.08 and (ii) 3.06. This meant that the individuals were swayed by the Bamum effect and also that they could not distinguish between 'genuine' and 'false' horoscope readings! I could cite many such examples to illustrate that astrology has been tested for the scientific criterion of predictability in numerous ways by numerous research workers on numerous occasions and has always been found wanting.

Individually or as part of a larger group, man has always lived by certain traditional beliefs. These beliefs are inextricably mixed with his cultural and religious heritage. Inevitably conflicts arise whenever the critical appraisal inherent in the scientific temper is applied to these beliefs. Some discrepancies appear because the beliefs or. the rituals they imply used to have a rational basis in the olden days. Some rituals may have had a symbolic or even a practical meaning in the social ambience of several centuries ago, but today they have become irrelevant. The question arises: What should one do in case such a conflict arises?

This issue has become more urgent in view of what Alvin Toffler calls the *future shock*. The rapid inputs from science and technology in the last century—more so in the last few decades-have had severe repercussions for human societies the world over. How to adjust to the rapid growth of knowledge, to the many ways energy can be used to upgrade human existence, to the many effective ways man may destroy human existence, to the negative environmental impact of all this on our natural habitat? These are questions that perhaps could have been handled had the societies been granted the luxury of ample time. This, unfortunately, is not the case. The response has to be quick in a rapidly changing scenario.

So how does a society absorb the new while holding on to the traditional? On the traditional side we have the virtues of the individual's responsibility to the society, the society's commitment to ensure the well-being of its members and the individual and social commitment to preserve the natural habitat around us. Armed with these qualities, man can assess what science has to offer; he can take judicious decisions on what to accept and what to reject. This is where the scientific temper helps society as a whole.

The technologically advanced nations of the West have been experiencing the ill effects of the uncontrolled impact of science and technology, such as the destructive nuclear arsenal, excessive industrial pollution, enforced idleness brought about by automation and the consequent psychological problems of mechanization. Does this mean that we must put a stop to all scientific and technological development? Such a response, already advocated by a few in the developing nations, indicates a panic reaction. Given the traditional virtues mentioned above as guiding principles, it should be possible to identify a rational path that skirts these pitfalls.

The Present Status

Let me review briefly how we Indians stand today vis-à-vis Nehru's expectation that only when we are politically and economically free will the mind function normally and critically'.[8] A dispassionate survey presents a somewhat mixed picture. On the one hand, we have several non-governmental organizations devoted to spreading rationalism and to eradicating superstitions. These organizations conduct public awareness programmes through lecture demonstrations, street plays, and experiments debunking the so-called miracles, articles and books on the importance of the scientific temper, and so on. Some agencies also provide grants for projects that bring science to the layperson. For example, the National Council for Science and Technology Communication (NCSTC) in New Delhi has been supporting such programmes in an imaginative fashion. Thus on National Science Day there are public awareness programmes throughout the country. Scientific institutions hold open houses for the general public. Institutions organize special quiz programmes and competitions for schoolchildren.

While there are several such efforts in an organized manner both in and out of the government, what is the mindset of the person in the street? Can we confidently assert that in the half century since Independence we have made a significant dent in the wall of superstitions that have steadily thickened over the centuries? Alas, the wall still stands firm.

But perhaps of greater concern is the rising trend of superstitiousness among Indians, especially of the younger generation. Several symptoms can be cited of this.

1. More marriages are being decided by matching of horoscopes than they were a generation ago. I know couples who did not base their marriages on 'findings' of horoscopes, but their children feel it necessary to apply this criterion to their marriage.

2. Despite debunking of miracles by science, numerous educated urbanites continue to believe in the babas who demonstrate their superhuman powers through miracles.

3. With new technology, new superstitions are taking hold in society. A recent rage is *Vaastu Shastra* and its Chinese counterpart, feng shui. Influential politicians and leaders of society have been swayed by these belief systems.

4. The legitimization of astrology as a science by the University Grants Commission is another symptom of this unfortunate trend."

One could easily enlarge this list. Granted, there are problems with excessive reliance on automation, there are dangers of pollution with indiscriminate uses of technology, there may be serious dangers for the society from continuing certain areas of scientific research, but this does not mean that we should turn away from the scientific path and grasp the age-old superstitions that have been proven to be invalid. The real challenge for India lies in facing up to the real problems and solving them through a rational scientific approach.

The Miracles of Science Benefit All

Indeed, at first sight some problems before us appear formidable, if not insurmountable. Yet we have only to look at the remarkable progress of science over the last few decades to see that a properly channelled scientific approach holds out hope for the future. We have witnessed scientific miracles happening before our own eyes and achieved in less than the span of a generation—the achievements of space technology with such highlights as the manned trips to the Moon; the landing on Mars and the Satellite Instructional Television Experiment (SITE) programme in our country; the rapid growth of communications that has dramatically brought the far corners near; and the advances in medicine, biology and agriculture.

Unlike the 'miracles' of the so-called god-men, the miracles of science benefit not just one individual but a whole class of humanity. They benefit the poor as well as the rich. Electric power not only runs the gadgets of the rich but also provides light to remote villages. The developed nations recognize these facts, and consequently they not only support science in general but also continue to encourage basic research, which may not have readily apparent applications. For us to ignore basic research would mean that we shall have to keep on importing new ideas from abroad. This would be contrary to our policy of self-reliance. India has plenty of untapped talent for basic research. Suitable support for basic research will unearth this talent and bring in its own rewards.

When Lord Krishna finished telling the Gita to Arjuna, he ended by saying: 'Reflect over what I have said fully and then do what you wish.'[12] In a sense this is what the scientific temper calls upon us to do—to weigh in all the evidence and then decide what is best.

12. The Oxymoron of Vedic Astrology

In February 2001 the University Grants Commission (UGC) announced that it was instituting Departments of Vedic Astrology in Indian universities and subsequently renamed the subject *iyotirvigyan (jyoti* meaning *light* and *vigyan* meaning *science),* as if to underscore its scientific nature. The annexure to the announcement contained details on the objective, scope, courses and their durations. Allowing for the quality of English that would have made Professor Higgins turn in his grave, the announcement promised that Vedic astrology is 'not only one of the main subjects of our traditional and classical knowledge but this is the discipline which lets us know the events happening in human life and in the universe on timescale'.

Many laypeople confuse astrology with astronomy. Let us reassure ourselves that the UGC circular means the former, not the latter. Certainly astronomy does not talk of events in human life, nor does it add 'new dimensions for research in the fields of Hindu mathematics, Vastushastra, Meteorological studies', as claimed in the UGC circular. It also promised that the course would bring benefits to professionals like doctors, architects and financial analysts. Such claims are made by astrology, which the *New Oxford Dictionary of English* defines as 'the study of the movements and relative positions of celestial bodies interpreted as having an influence on human affairs and the natural world[1]. It describes astronomy, on the other hand, as 'the branch of science which deals with celestial objects, space, and the physical universe as a whole'.[1] It is necessary to make this distinction at the outset, for my contention is that Vedic astrology is neither Vedic nor vigyan.

Astrology Is Not Vedic

In chapter 2 we have outlined mathematician S.G. Dani's arguments debunking Vedic mathematics. He showed that one should be very wary of anything declared to be Vedic or of ancient origin. Since India had an oral tradition of transmission of knowledge, very few reliable records of this ancient epoch are extant. The situation is thus different from that prevailing in other cultures like China, Arabia or medieval Europe where written traditions existed. What written works we have may well contain the *prakshipta* (later additions to a manuscript). In this light let us examine the claim of Vedic astrology to be of Vedic origin.

A survey of Vedic literature fails to reveal instances of nine 'planets' and their supposed influence on human destiny. There are references to omens and also to sacrifices to be performed at different times of the year as determined by the positions of constellations. The seven-day week came to India from the Greeks through the Arabs. This division of time is related to 'planets'. (The Sun and the Moon were included in these nine planets.) The concept of the occult influence of the planets is of European origin. This is indicated by a shloka from the Surya-*Siddhanta* in which Surya (the Sun god) is telling the asura Maya 'to go to Rome [which was symbolic of Greco-Roman culture), your own city, where, because of a curse of Brahma I will reveal to you this knowledge in the guise of a Yavana [the name given to a foreigner or non-Indian often applied to a Greek]'.[2] The Sanskrit scholar C. Kunhan Raja has stated in unequivocal terms that '[t]here is no astrology of Vedic tradition' and that there have been inputs of astrological nature from outside the Vedic culture. Alexander's invasion of India in the fourth century B.C. opened the way for flow of ideas, good and bad, from Greece to India. It is, therefore, all the more ridiculous that by calling astrology *Vedic* we are laying claims to an imported superstition.

In fact, authentic records tell us more about Vedic astronomy, which involved the observations of stars and constellations vis-à-vis the Sun and the Moon and their use for time keeping and calendar making. There has been controversy here too, with some scholars like David Pingree who claim that all ancient Indian astronomy was essentially borrowed from the West.[11] Other scholars deny this assertion and maintain that Indian astronomy from the *Vedanga Jyotisha* to the golden age—from Aryabhata I (fifth century) to Bhaskara II (twelfth century)—developed indigenously with considerable originality. But all these claims and counterclaims are about astronomy and not astrology.

Indeed, the Greek word *planet* means *wanderer,* a notion the Greeks arrived at by long-term observations of these heavenly bodies changing their positions somewhat arbitrarily relative to the stellar background. The Greek response to these findings was two-fold, one based on astronomy and the other on astrology.

The astronomy component sought to fit the apparently erratic planetary motion within the framework of the Aristotelian hypothesis that all natural motions are circular and that the earth is at rest at the centre of the universe. So here was a challenge to the astronomers of the day: Explain the motion of a planet by assuming that the earth is fixed and the planet moves in a circle. They met the challenge by introducing epicycles, a series of circles with each circle in the series having its centre moving on the preceding member in the series and with the planet itself moving on the last one. It was an ingenious but tedious exercise in what today's physicists would call parameter *fitting,* but it was rendered redundant with the emergence of the heliocentric theory of Copernicus, Galileo, Kepler and Newton.

The astrology component, on the other hand, took recourse assuming that the irregular motion of planets owed its existence to the special power the planets possess that allows them to move at will. Then followed the belief that this power extended its effect to humans by governing their destiny. So here we see some reason for the origin of astrological beliefs. Today planetary motion is fully understood, and it is well established that—far from possessing any special power to move at will—a planet moves in a completely predictable fashion bound by the Sun's gravitation. Moreover, man is now able to send spaceships to observe the planets closely. Such is the human psyche that, despite all these facts, it has not eradicated astrological beliefs. In short, while one can understand some logic, howsoever convoluted, in the early beliefs in astrology, there is no logic at all in justifying that belief in today's post-Newtonian (post 1685) era. This brings us to the second of our questions: Is astrology a science?

Why Astrology Is Not a Science

The scientific community was up in arms against the UGC's validation of Vedic astrology not so much on the issue of its being Vedic or not, as on its projection as a science. Let us first examine the arguments that supporters of astrology make when astrology is rejected as a science. These are usually of the following kind:

Astrology makes use of the positions of planets obtained by scientific observations, just as astronomy does. So if astronomy is a science, why not astrology?

There is always someone who has heard of some astrologer whose prediction had come true. For making such correct predictions, shouldn't astrology be credited as being a science?

Weather forecasts go wrong, and medical diagnoses are known to fail and vary from doctor to doctor. Since these subjects are regarded as sciences, why exclude astrology?

Some astrologers fail because they are bad practitioners of the subject. Although it is unfortunate that there are charlatans in the field, the subject itself is fully scientific.

Scientists are an arrogant lot who have rejected astrology without studying or testing it.

To deal with these objections, it is necessary to spell out what is required of a subject to be called a science. Science has evolved over the centuries through a process of theorizing, experimentation and observation.[5] In practice there are many hiccups and wrong turnings, and in reality the history of science is littered with falsified theories, misleading experiments and wrong observations. Scientists are the first to admit this fact. They also admit that at no time can science claim to have solved everything. Experience has shown that new questions always arise as we learn more about a subject.

So what is the strength of what we call science? It is its self-imposed discipline that works in the following way. A scientific theory must clearly state its basic assumptions consistent with the evidence. It should present a logical framework of arguments leading to falsifiable predictions. The theory should not indulge in tautology, nor should it change its basic tenets each time it is called upon to make a prediction. In other words, there is uniqueness about its assumptions. Its predictions are subject to tests, which require experiments and observations that are objective and can be interpreted by statistical analysis. Even with all these safeguards, no theory is perfect. Newton's law of gravitation was improved upon by Einstein's theory of general relativity after a large number of controlled observations. Despite these successes, no scientist today would claim that relativity represents the last word on gravitation. For example, one does not know how to adapt the theory to the rules of quantum physics. Quantum gravity, which specifies how gravity functions on a micro-scale, poses the next challenge to be surmounted by any theory claiming to improve on general relativity.

Let us now come to the comments on behalf of astrology. Astronomy follows the rigorous discipline of science, but astrology does not. There is no unique set of basic rules for astrology or a logical set of rules for interpreting data that is fully objective and independent of a specific astrologer. Failed astrological predictions are not seen as disproving a theory. Rather supporters of astrology-see their subject as perfect, and if a prediction based on it fails, this is because the subject is wrongly interpreted. Since interpretations vary from person to person, textbooks cannot be designed for the proposed course, and teachers cannot agree upon a uniform, universally accepted approach.

Likewise, astrologers have probably not heard of British philosopher Karl Popper (1902-94), or if they have, they have chosen to ignore what he said about scientific theory. The Popperian view is that a scientific theory has to be abandoned if it fails on a single prediction. Thus successful predictions are necessary but not sufficient for the survival of the theory. When asked how many unsuccessful predictions a particular astrologer has made, most believers would prefer not to answer.

Similarly, weather forecasts and medical diagnoses are not perfect, but these subjects do follow the disciplines of science. In weather forecasting, complex calculations are made of the various atmospheric and ground conditions. Although the forces controlling them are not fully understood and satellite observations have not been perfected, even detractors of meteorology as a science admit that the quality of weather forecasting has steadily improved as a result of more sophisticated theories and observations. Medical science also does not claim to be perfect, but because of progress in biology and biotechnology, we understand the human body better, and consequently diagnoses and treatments have consistently improved. Astrology has not shown any improvement in its performance with inputs from science and technology.

If every correct prediction proves that astrology is a science and a wrong prediction means that the astrologer is a charlatan, then there is no astrologer left who cannot be branded thus. Should not the practitioners of the subject take a critical look at what they preach?

Finally, substantial documentation shows that scientists have examined astrology to verify the correctness of astrological predictions, but every test has failed to prove the veracity of astrology.

Astrology's Appeal

Why has astrology survived (and even flourished) despite such scientific debunking? This is a good question for social scientists to study. Here are a few thoughts. In addition to the Barnum effect, according to which the human mind selects those items that apply to the individual and ignores the discordant part, astrological predictions are frequently worded in such a way that something in them is applicable to everyone.' In addition, astrology is looked upon as a psychotherapeutic exercise, which brings solace to people when they are confronted with stressful situations, such as taking crucial decisions or the effects of deep sorrow or disappointment. Rather than worry or brood upon difficult issues, astrology relegates responsibility to the planets or to someone who claims to interpret their effects and take away the onus from the person in distress. On such occasions logic is the last thing on one's mind.

It could be argued that astrology will continue to exist and flourish because people seek solace in it. However, if man wishes to lay claims to the title of a rational animal, then there is cause to worry, for there has so far been no rational justification for astrological statements. Indeed promoting astrology as part of higher education and encouraging its decision making process for architecture, weather forecasting and stock market investments is a sign of regression. In the West, belief in astrology does not enjoy the stamp of respectability that it does here. In India, it is taken seriously in all walks of society and transcends all divisions with respect to gender, caste, education, income or politics. For a country that is trying to catch up with the developed nations, a rational and efficient management of human resources is essential. This can hardly be achieved by basing decision making on superstitions.

13. Science Journalism: Educating the Public

In 1976 I delivered the tenth Jawaharlal Nehru Memorial Lecture in Delhi. My lecture, 'The Role of Scientific Outlook in the Development of Science and Society', was open to everyone, and copies of it were freely distributed afterwards. As I was leaving, a newspaper reporter approached me for a written version. I was familiar with this kind of request. Although billed as a public lecture, the journalist assumed that he would not understand what a scientist had to say, so he wanted something in writing from me to ensure that his information was accurate. On this occasion I felt myself well prepared. I triumphantly pointed out to him that a copy of the entire talk was available to him then and there.

'I know it, sir,' he replied politely producing a copy from his bag.

'Then what is your problem?' I asked.

'Well, sir, I have to report the lecture in 100 words, and I do not know how to shorten it. Could you tell me the gist of what you said?'

I gave up after that! I never expected to have to spoon-feed reporters. This incident illustrates the dismal state of science reporting in the country. Although there are a few exceptions, the standard of science journalism is very low. It is against this background that I have ventured to set forth my comments on science journalism in India.

By way of context, let me say something about the almost universal fear felt by laypeople that they are not sufficiently equipped to understand and appreciate anything that has to do with science. When science is taught in our schools, most students look upon it as a mysterious subject to be memorized by heart and reproduced like a trained parrot. They sense none of the thrills of science, the agonies of unsolved problems or the ecstasy of finding the right solutions. So schoolchildren grow into adults who are happy to be relieved of the burden of science.

I recall a venerable professor of Sanskrit who greeted me before my talk at the Vasant Vyakhyanmala in Pune with the remark, 'I am looking forward to your talk, not that I will understand any of it'. My topic was 'What Would Life Be Like a Hundred Years Hence?' Even educated adults of non-scientific background are inhibited by such subjects, thinking that they are too difficult to understand and that a scientist's talk is bound to be unintelligible.

Science journalism does not mean only simplifying science and explaining it to the layman. It is not supposed to be a pedagogical exercise. Let's consider what it should be.

The Age of Science

We live in the age of science. No one described the impact of science and technology more graphically than Alvin Toffler in *Future Shock.* Let me summarise his description of the way science and technology have come increasingly to determine the conditions under which we live;

Divide the last 50,000 years or so of known human existence on this planet into some 800 human lifespan—each lifespan comprising 62.5 years. Take this lifespan, for which some historical information is available, as a representative unit of time. Of these 800 time units, the first 650 or so man spent in primitive conditions in caves. The art of writing is not more than seventy life spans old and that of printing only six life spans old. The electric motor is two life spans old. In fact, most of the things we use in our daily existence involve technology much younger, some of it not more than one lifespan old. The discovery of atomic energy, the use of space technology and the proliferation of computers are all less than a lifespan old.

This indicates how rapidly scientific ideas are being translated into technological inventions and how quickly we are assimilating them into our lives. Yet the rapidity with which this is taking place is not proving entirely beneficial to the society. Rather the situation resembles that of a human being confronted with a feast of excellent eatables served in rapid succession and being tempted to eat them as fast as they come. The banquet may look dazzling, but the diner ought to pick and choose, keeping in mind his limitations of health and capacity to digest. This human society has not learnt to do. The diner may ask, 'How do 1 know what is good for me, how much of it is good for me, and what items I should avoid?' The role of science journalism is to help him answer these queries intelligently.

The support for research in science and technology in a typical country is broadly provided by the government, although the private sector also contributes small fractions depending on the economy of the country. So by and large taxpayers are the ultimate source of the funds. To what extent should they exercise control on the funding? How can they make wise collective decisions today to ensure a better tomorrow?

With rapid changes taking place in science and technology, forecasting their effects even ten years from now is not easy. Yet some assessment of how things will go in the future is necessary for planning. For example, Prime Minster Rajiv Gandhi's Science

Advisory Council undertook such an exercise from 1986 to 1989. In a paper entitled 'An Approach to a Perspective Plan for A.D. 2001 the council stated,

It is clear to us that not everything that we plan can be accomplished by government machinery alone. We need to fully exploit the potential of voluntary movements in crucial areas such as population control, family welfare, school education and adult literacy. It is likely that many of these tasks are better executed by motivated citizens, especially the educated women who are not yet fully used for the benefit of our society.[3]

So here we have another role for science journalism— to educate people about future prospects so that they are prepared for them and can take wise and far-reaching decisions now.

Reporting on Scientific Events

The technological marvels of today have roots in past scientific discoveries. Very often the former is highlighted while the latter is ignored. In fact, while a discovery was being made, the discoverers and their contemporaries had no idea what the implications of the development would be. Here are a few examples of how even the leaders in their fields failed to correctly assess the prospects of a discovery.

Aircrafts are impossible.

The demonstration that no possible combination of known substances, known forms of machinery and known forms of force, can be united in the practical machine by which man shall fly long distances through the air, seems to the writer as complete as it is possible for the demonstration of any physical fact to be.

-Simon *Newcomb* (1835-1909)

Alternating currents are too dangerous to be of any use.

There is no plea which will justify the use of high-tension and alternating currents, either in a scientific or a commercial sense. They are employed solely to reduce investment in copper wire and real estate.

My personal desire would be to prohibit entirely the use of alternating currents. They are unnecessary as they are dangerous.... I can therefore see no justification for the introduction of a system which has no element of permanency and every element of danger to life and property[1].

I have always consistently opposed high-tension and alternating systems of electric lighting, not only on account of danger, but because of their general unreliability and unsuitability for any general system of distribution.

-Thomas A. *Edison (1889)*

Intercontinental ballistic missiles are too hard to make.

There has been a great deal said about 3000 miles high-angle rocket. In my opinion such a thing is impossible for many years. The people who have been writing these things that annoy me, have been talking about a 3000 miles high-angle rocket shot from one continent to another, carrying an atomic bomb and so directed as to be a precise weapon which would land exactly on a certain target, such as a city.

I say, technically, I don't think anyone in the world knows how to do such a thing, and 1 feel confident that it will not be done for a very long period of time to come .... I think we can leave that out of our thinking, 1 wish the American public would leave that out of their thinking.[6]

—Dr *Vannevar Bush (1945)*

The atomic bomb will never explode.

That is the biggest fool thing we have ever done. The bomb will never go off, and I speak as an expert in explosives.[7]

—Admiral *William Leaky to President Truman (1945)*

Nevertheless, there are a number of cases where the future implications of the discovery can be correctly imagined. The implications may not be practical; they may only represent an advance in pure knowledge. When Stephen Hawking found that a black hole can radiate energy, the result was hailed as an important advance in our understanding of how the quantum processes operate in strongly curved space and time, near black holes for example. Why did scientists feel excited by the result even though there was no chance of observing it in operation at the time? Because of the hint it holds of combining two of nature's mysteries: quantum theory and gravity.

There are occasions, on the other hand, where a new discovery, serendipitous though it is, opens up numerous technological fallouts. The discovery of high-temperature superconductivity was of this kind. Normally material becomes superconducting, that is, it offers no resistance to any electric current flowing through it, at very low temperatures, going close to absolute zero. In the mid-1980s, the possibility emerged that certain special types of material show this property at much higher temperatures, say, a hundred degrees above the absolute. This opens out the possibility of operating many devices without loss of energy as heat, for example.

Scientific events of either kind are worth reporting. Although laypeople may not appreciate the details, they should be given a chance to capture the excitement of creativity, of unravelling one of nature's secrets, of the vista of future applications that are opening out. Such reporting brings science one step closer to humanity—a step away from the ivory tower in which humanity has placed it. Indeed that was the motivation behind my choice of the topic of my talk in the Vasant Vyakhyanmala.

Scientific Frauds

Investigative journalism these days covers many cases of corruption, crime, spying, conspiracy and war stories. Once in a while the scientific world also offers challenging and highly interesting cases. Sometimes a claim to an important discovery is made but without proper substantiation, or a result is based on fraud or is a genuine mistake. There are even cases of scientific plagiarism.

For instance, in 1903 the eminent French physicist Rene Blondlot claimed to have discovered a new type of radiation called N-rays. Coming shortly after the identification of X-rays in Germany, this discovery of new rays with remarkable properties was hailed widely in France, in part because of the competition between these neighbouring countries in many fields including science. N-rays became fashionable and a large number of research papers on them began to appear in French journals. Soon Blondlot was awarded the prestigious Lalande Prize by the I'Academic franchise.

However, a scientific experiment is nothing if it is not repeatable. This was not happening in the case of N-rays. The rays could not be detected in similar experiments in Great Britain or Germany. Thus British researchers requested that R.W. Wood, a distinguished American scientist, visit Blondlot's laboratory and inspect the experiment. (A scientist from a rival country like Britain or Germany would not have been welcome.) Wood made the trip and found that the claim for N-rays was totally false. His own account of how he detected this fraud makes a very-interesting reading even for the layman. It turned out that the N-rays did not exist and the entire set of evidence was fabricated.

The temptation to make spectacular but fraudulent claims is stronger now than in the relatively placid times a century ago, because scientists are judged by their performance much more stringently today. Awards, peer support, promotions and project grants are all linked with performance. Thus if Mr X has made a stupendous discovery, he stands to attract a lot of financial support and wield power in the scientific circles, so there is every incentive for him to rush out and make premature announcements. In spite of these temptations, science has remained relatively clean, mainly because a scientific fraud is detected sooner than later. Journalists can very well assist in detecting it sooner.

Investigative journalism can also help the public by testing the claims of unidentified flying objects (UFOs) as extraterrestrial spacecrafts. Sightings of UFOs are reported in the press from time to time. People get excited by the suggestion that these are spaceships from some alien civilizations beyond Earth. The real explanations may be quite mundane; the object may be Venus, an optical illusion (like a mirage), a man-made spy satellite or simply the figment of a highly fertile imagination. In *UFOs Explained,* American journalist Philip Klass gives absorbing details of investigative reports that remove the mystery around several such claims.[9] He also shows how photographic evidence can be faked.

Debunking Miracles and Fighting Superstitions

India has a special problem of its own in the so-called holy men who take advantage of the gullible by producing miracles in apparent defiance of science. They can wield considerable evil influence on individuals and the society. Scientists and magicians together can play a valuable role in debunking such cases, and journalists can get a good story in the process. For example, Uri Geller claimed to have supernatural mental powers by which he could bend spoons at a distance. Some scientists were initially fooled by him, and it took the magician James Randi to demonstrate the trick. This case illustrates that considerable subtlety is employed in these deceptions and the claims have to be probed very carefully.

India is a curious mixture of scientific advance and deeply ingrained superstitions. The latter cannot be removed by fiat but can be countered by rational arguments. Take astrology, for example. Scientists have tested astrology in many different ways and found it devoid of any scientific basis. Yet to convince the believer that this is the case is not easy. Patience and the information that science journalism can provide are needed.

Technological Disasters and Boons

With high technology entering every field, there are man-made disasters also. The space shuttle Challenger exploded on take-off in January 1986, and Columbia ripped apart upon re-entry in January 2003. The Three Mile Island nuclear plant in the US and the one in Chernobyl in the USSR developed malfunctions that led to leakage of damaging radiation. The Bhopal gas tragedy of 1984 is still green in our memory. Sophisticated aircraft crash, rockets fail to take off, and railway accidents occur because of signalling faults. Potent medicines may turn out to have damaging side effects.

There are interesting and informative articles written on most of these disasters. The problem is how to give them as wide a circulation as possible. A valuable contribution science journalism can make to science and technology is to mitigate fears of the irrational type, discuss what went wrong and point to where the fault lay. Although this may not be easy since there may be vested interests keen to suppress the truth, this is when technical experts and journalists need to work together. It may not be possible to analyse and diagnose what went wrong immediately, but transparency and dissemination of factual information can go a long way towards allaying public fears. Discovery of the cause can elucidate the necessary corrective action or future precautions. In most cases, it turns out that the initial panic against science and technology is akin to throwing the baby out with the bath water.

Science dissemination at the popular level also should emphasize the positive aspects of science and technology. There are several ways of doing it. In Is Science Necessary?, Max Perutz gives a list of highly creative persons in the arts and sciences who died young—before science could provide remedies, ones that are taken for granted today. Modern science has also provided quick channels of communication that are pressed into operation whenever natural disasters like cyclones, volcanic eruptions or earthquakes strike. Journalists can highlight these positive aspects of science and technology. In our country, scientific inputs to plan for such disasters are at best peripheral largely because science and technology have not sufficiently seeped into the planners' minds. One still notices two cultures—the traditional and the scientific—and the latter is kept in a closed box to be opened on some purely ceremonial occasions.

The Status of Science Journalism Today

Let us first consider the advanced countries of the West. Writing about science journalism, R, Hanbury Brown has moaned,

Although advances in science and technology have given us an unparalleled ability to communicate with one another by radio, television and vast quantities of print, these so-called 'media' are seldom used to tell us anything about science .... As far as journalism is concerned, it would prefer science to go away; of the 1750 daily papers published in the USA only 50 employ full-time science writers. [Nevertheless, inl recent years there has been a marked increase in the number of programmes and semi-popular magazines devoted to science, particularly in the USA, which suggests that, may be, the popular media underestimated the market.

Compared to the West, the situation in India is even more dismal. As mentioned by Hanbury Brown, the market economy operates here too. Hence astrological forecasts appear regularly in our newspapers, but science and technology are touched, if at all, only with a barge pole. In a recent survey conducted by the Energy and Environment Group and the National Council for Science and Technology Communication (NCSTC) the fraction of space devoted to science coverage in the national newspapers from July to December 1989 was found to be in the range of 2.10 to 6.56 per cent of the total reading matter, exclusive of advertisements. Even in these reports on science, it is not known how much was of indigenous origin and how much was taken from foreign sources! Many reports in our newspapers come from the *New York Times,* the reports issued jointly by the *Times of London* and the journal *Nature,* and other news items or articles from Western media.

To provide our own sources of scientific news, the NCSTC launched Srot, a publication that has science coverage compiled and prepared in India. This experiment began in 1988 in the form of a monthly newsletter, to which media outlets were invited to subscribe. Srot contains science items for instant publication and, being in ready-to-publish format, relieved editors of the difficulties of locating sources.

The response, however, was dismal. At the end of the second year only some ninety clippings had been picked up. The reasons for the apathy were varied: First, being a monthly newsletter, the items in it tended to be dated from a news value point of view; second, the articles were longer than what the newspapers wanted; third, some newspapers would have liked the articles jazzed up to make them more exciting or dramatized, if not sensational. To get round these difficulties, Srot was revised into a weekly newsletter with shorter, crisper articles, and the response has improved. From December 1990 to October 1991, 336 clippings were picked up. However, the Srot editor pointed out that many clippings are used by the media without acknowledgement, let alone the payment of the modest royalty! Thus the extent of unauthorized use of Srot articles may be even larger.

The list of newspapers using the facility has some thirty-five names, largely from the Hindi belt in the north. In fact, science coverage in Hindi newspapers seems to be better than in the English-language ones. Whatever the present situation, the Srot experiment should be continued further in view of its impact.

Another silver lining in journalism is the regular weekly publication of science supplements by leading newspapers in different languages. Here I feel our scientists can contribute effectively in many ways—by writing articles on the latest developments, by giving interviews on their work and even by helping to answer readers' queries.

This last point needs to be underscored heavily. Scientists themselves, with the large public funds supporting them, owe it to the public to inform them about their work. By remaining in their ivory towers they foster a growing feeling that science is a luxury that society cannot afford. Rather, it is the other way round! Science is something that we cannot afford to abandon. To make the correct decisions about the country's development, to employ the right strategy with regard to the controlled use of the rapidly growing science and technology and to nurture the vital spark of scientific creativity, scientists have to keep the public well informed about critical issues. The media should help scientists in this crusade. Newspapers play a nodal role in spreading information and opinion in times of stress. They should not treat science journalism as quiet backwaters but look upon it as an ocean vibrant with waves and tides that determine our destiny.

PART III

The Future of Science in India

We now turn to an examination of issues that will become increasingly relevant as the impact of science on society grows. Indians need to adapt themselves to this rapidly changing scenario. We have already stressed the need for scientific temper and deplored the backward steps taken by many (even educated) Indians towards superstitions like astrology. Looking to the future, our society needs to appreciate the role of fundamental research and its necessity in sustaining a science and technology infrastructure.

The first chapter in this section illustrates the important role of astronomy as a fundamental science. Next we consider the contribution of science fiction to our understanding of science. It is not simply a light source of entertainment but a powerful medium through which intellectuals can alert their societies about possible dangers. At the same time, it can draw attention to new and beneficial scientific ideas. We discuss this issue in the Indian context, where science fiction as a genre is relatively young. The last chapter emphasizes the need to be adventurous with new ideas in science: to prevent getting carried away by scientific fundamentalism. How does society adjust its need for spiritual solace with the apparently entirely materialistic view of science? Perhaps we can find a strategy of coexistence.

14. Why Study Astronomy?

Man has long asked who we are and what our place is in the universe, both geographically and metaphorically. Consequently, astronomy developed as a science as much through human fascination about the cosmos as through the realization that observing the sky can bring in knowledge that is useful to the society. For the stars and constellations change their position in the sky cyclically over time, and by observing these patterns man could make calendars. Early agriculturists wanted to know how the seasons progressively change through the year so that they could sow and harvest at the right time. Even today the nakshatras (constellations) guide the farmer in such operations.

In Indian society, astronomy provided information on determining the so-called auspicious times for performing the various rituals, as these times were linked to the positions of heavenly bodies. In fact, considerable progress in early mathematics is linked to the rituals like yajnas.[1] Indeed, this was the way that astronomy established an intimate relationship to mathematics, which has survived and prospered to this day.

As an astronomer and astrophysicist, I propose to use this chapter to answer some frequently asked questions: What is the use of star gazing and trying to understand cosmic phenomena? How can an apparently esoteric field like astronomy bring benefits to not only scientists but also society at large? Can a poor country like India afford to spend money on an esoteric subject like astronomy? These questions, as will be obvious from their answers, hold a special relevance for India.

From Kepler to Modern Times

More than two millennia ago the Greeks derived the word planet from a term meaning *to wander* because they did not, or could *not,* see a prima facie pattern in their motions. Guided as they were by the natural philosophy of Aristotle, they tried to fit the heavenly bodies into a pattern of circular motions. Aristotle believed that all natural motions were circular and that any departure from a circular path indicated the presence of a perturbing agency. This latter type of motion he termed *violent* motion. The Greeks noted that star trajectories fell in neat circular arcs from East to West. This was consistent with Aristotle's natural motions. The planets, however, did not show such simplicity. Relative to stars, their paths were twisted, sometimes reversing, sometimes going up or down. The planets, therefore, were wanderers in the sky. It is probably because of this extraordinary nature of planetary tracks that people came to believe that the planets possessed extraordinary powers that they wielded on the mortals. The age-old belief in astrology may be understood this way.

To their credit, the Aristotelians were not swayed by this belief and sought to fit the wayward planetary trajectories into the circular pattern. Thus grew the concept of epicycles. Instead of a single circle, the planet, they argued, moved on a circle whose centre moved on another circle, whose centre moved on still another circle, and so on. It depended on the skill of the geometer and the required accuracy of the model vis-à-vis observations as to how far this sequence of circles would go! These circles came to be known as epicycles and the theory as the epicyclic theory. In short, Greek astronomers were faced with the challenge of understanding the somewhat arbitrary motions of planets; and they tried to meet it through the intricate geometric constructions of epicycles. In the terminology of the modem theoretical physicist, their theory had epicycles as parameters and to achieve the desired accuracy the number of parameters had to be increased.

The Greek obsession with circles, looked at this way, was conditioned by the faulty Aristotelian belief in circular motion. It was further complicated by the geocentric theory that supposed that the earth is fixed in space and that all planets and the Sun move around it. Copernicus got rid of the latter but retained the former. That is, although he assumed that the planets go round a fixed sun, he retained the epicycles. This made his geometrical constructions somewhat simpler but still not elegant; the epicycles were a reminder that this was a contrived way of looking at reality.

This is where we appreciate the contributions of Johannes Kepler. He was keen to work on planetary trajectories to look for an underlying simplicity of their construction. He was aware that this required detailed observational studies. Such observations had been carried out by Tycho Brahe, so he enrolled with Brahe as an assistant. Brahe himself was convinced that Copernicus' heliocentric theory was wrong and hoped that his own data would disprove it. He was in need of an assistant with computational ability and was glad to employ Kepler.

Working with Brahe was not, however, a pleasant experience, what with his whimsicality and derogatory behaviour towards his subordinates. But Kepler stuck to his job as it provided him access to Brahe's data, which was a veritable gold mine. As luck would have it, Brahe died not long after Kepler joined him, and on his deathbed he enjoined his assistant to do his best to disprove Copernicus.

After Brahe's death, while his relatives were engaged in disputes over his possessions, Kepler quietly took hold of the valuable data and spent the next two decades carefully analysing it. Out of these marathon efforts emerged the three laws of planetary motion that are now named after him. In a sense Kepler kept his promise to Brahe—he proved Copernicus wrong—but not in the sense that Brahe had intended. Kepler verified that the heliocentric theory advocated by Copernicus was correct, although the Copernican epicyclic approach was wrong. Kepler's first law of motion sets this out clearly. It tells us that a planet goes round the Sun in an elliptical trajectory. The Sun is at the focus of the ellipse. Thus the series of epicycles represented an approximation to the reality of an ellipse. Kepler's second law describes how a planet moves along its path: The line joining it to the Sun sweeps out equal areas in equal intervals of time. His third law relates the time taken by the planet to complete one revolution to the size of the orbit.

I have gone into these details because the emergence of these simple-looking but quantitative rules demonstrates the result of Kepler's persistent efforts. Out of the noise in Brahe's data, he extracted the real signal—the pattern of planetary motion. More importantly, the stage was now set to ask why the planets move around the Sun in this way.

It required the genius of Isaac Newton to answer this question. We have all read the story of how Newton discovered the law of gravitation when an apple fell on him while he was sitting in his orchard at Woolsthorpe Manor during his *anni mirabiles* (1664-66). Could the fall of an apple inspire an inverse square law? The story, if true, may go so far as suggesting that it led Newton to think of a force of attraction between the earth and the apple, but nothing more. Even the most sensitive instruments of today's technology cannot tell us that the fall of an apple implies the inverse square law of attraction. For this quantitative deduction, Newton needed more detailed data, and those were available to him in Kepler's work.

Today a mathematics undergraduate can deduce the inverse square law of gravitation from the three Keplerian laws. For Newton.it was the work of a genius, as he used calculus, a new branch of mathematics, invented by himself for this work. Later he demonstrated the converse problem, that given the law of gravitation and the laws of motion, the Keplerian laws follow. Thus he showed that the gravitational attraction of the Sun is the prime mover for all the planets.

So by the end of the seventeenth century, the riddle of how the planets move and why they do so was fully understood. Far from being wanderers moving at their own free will, the planets were seen as inert masses forced to move in well-defined trajectories by the Sun's force of attraction. If there was any justification for believing that planets wield any influence on us humans, this demonstration should have disproved it. Yet such is the human mind that many still believe in that myth today!

The Newtonian law of gravitation was inspired by Kepler's laws of planetary motion and received further confirmation through more astronomical observations, like the sighting of comet Halley, the discovery of planet Neptune, the motions of binary stars and so on. Although the famous experiment by Henry Cavendish measured the strength of the gravitational force in the laboratory, the confidence in the validity of the Newtonian law grew solely because of astronomical data.

We now come to the recent years of space technology. That we can launch satellites around the earth and send spacecraft to the Moon and Mars, Mercury and Jupiter, all in highly precise trajectories, is because of the validity of Newton's law. So the benefits we enjoy today from space technology—be it remote sensing of Earth's resources, sending a fax or an e-mail message across the globe or watching the World Cup live on TV—all these owe their existence to the law of gravitation, which itself owes its genesis to the data from astronomy. In the mid-1970s the SITE demonstrated how education can be provided to remote and inaccessible places in India through TV programmes beamed directly to them by satellite. And so although astronomy may appear esoteric, its pursuit adds to our storehouse of knowledge and benefits human society.

The Source of Solar Energy

The question of what keeps the Sun shining has been a major challenge to astrophysicists, whose job it is to understand the behaviour of celestial bodies in terms of the laws of physics. Although the problem has now been solved, its history is interesting.

In the last century, two distinguished physicists, Lord Kelvin in Britain and Baron Hermann Ludwig Ferdinand von Helmholtz (1821-94) in Germany offered a solution to the problem. They argued that the source of solar energy lies in its vast gravitational energy reservoir. In a gravity dam, water falling from a great height can run electric turbines and thereby convert its gravitational energy to electric energy. In the same way, Kelvin and Helmholtz demonstrated that as a massive ball of matter like the Sun slowly shrinks, it releases gravitational energy, which can be converted to light energy. On the face of it, the calculation was impressive as it showed that the Sun could draw on this energy for about twenty million years if it were to keep shining at its present rate. However, in the last analysis, the idea did not work! For by the beginning of the twentieth century it was becoming clear that the earth and the solar system were considerably older than twenty million years. Today we know that the age of the solar system may be close to five billion years. Thus the gravity reservoir of the Sun is far from adequate for keeping it shining for so long.

In the 1920s the problem of solar energy was tackled anew by Cambridge astronomer Arthur Stanley Eddington. Eddington set up equations describing the internal structure of a star like the Sun. These equations visualized the Sun as a ball of hot plasma (that is, a system of atoms of gas from which the outer electrons have been stripped off and kept as a separate entity), which was held in equilibrium under the opposing forces of its own gravity and the pressures of plasma and radiation. They also showed how to describe the passage of radiation from the deep interior to the outer layers of the star, eventually escaping from the surface as starlight. Using these equations, Eddington was able to estimate the pressure, density and temperature of the gas from the outer layers all the way towards the centre. All these physical measures rise rapidly as we proceed inwards. For example, a star like the Sun may have an outer surface temperature of 5500 °C, but its central temperature could well exceed 10,00,000 °C!

Normally the nucleus of an atom is a tightly bound entity. In a typical chemical reaction the nucleus as a bound unit is not affected. However, at energies considerably in excess of chemical energies, such as those of particles in a gas of 1, 00, 00,000 °C temperature, even the identity of a nucleus is threatened. In particular, it may be possible for two smaller nuclei to combine into a bigger one, a process known as nuclear fusion.

Eddington believed that nuclear fusion would operate in the core of a star and, in particular, the process would result in the formation of the nucleus of helium from the fusion of hydrogen. This possibility had earlier been suggested by French physicist Jean Baptiste Perrin (1870-1942). However, when four nuclei of hydrogen combine to form one nucleus of helium, some mass is lost. Using the law of conservation of matter and energy via Einstein's equation $E = Mc^2$, Eddington argued that the mass loss would be compensated by energy, which is what the star radiates.

There was one snag, however. The science of nuclear physics was in a very primitive state in the 1920s. Based on what they knew, atomic physicists very much doubted if Eddington's ideas would work. For the hydrogen nuclei are positively charged and any two of them would repel each other. Unless the nuclei are hurtled towards each other very fast, they would not fuse together, and in a hot gas the nuclei do move very fast. When they move at random, there are cases where two nuclei may approach each other. They could collide and fuse, but according to the atomic physicists, at temperatures of the order of ten million or more that Eddington was talking about, the speeds of these nuclei would not be high enough to surmount the barrier of repulsion for the fusion process to work.

Eddington, however, was confident that he was right. In *The Internal Constitution of the Stars,* he wrote, 'We do not argue with the critic who urges that the stars are not hot enough for this process. We tell him to go and find a hotter place. '[2] A decade later Eddington was, indeed, proved right. For by mid-1950s the science of nuclear physics had advanced to a stage where scientists had become better acquainted with the force of nuclear binding. They found that there is a very strong force of attraction between the nuclear particles, a force far exceeding their electrostatic repulsion, which can facilitate fusion of two nuclei at the temperatures calculated by Eddington. In 1939, American physicist Hans Bethe (b. 1906) used the ideas of nuclear fusion of hydrogen to helium to generate realistic models of the Sun and stars. These models fully explained why the Sun keeps shining with its observed luminosity. This is yet another example of how astronomy has shown the way to basic science.

This brings us to the following multibillion dollar question: Can we carry out this process in a controlled fashion on the earth? That the process can operate in a controlled fashion in the Sun has been demonstrated over the last five billion years or so. The challenge now lies in repeating on the earth what has been demonstrated in an astronomical setting. It is easy for the Sun to achieve controlled fusion because of its strong gravity. Gravitational pressure in the Sun can contain and control the nuclear fuel. In a terrestrial experiment the controlling agency cannot be gravity, which is very weak on the earth. The present attempts revolve round containing hot plasma under a magnetic force. If the process succeeds, it may provide a cheap and unpolluted way of generating energy, for the heavy water abundantly found in the seas around us could be used as fuel. Again, with a shoreline of several thousand kilometres, one can see the enormous relief it would bring India as it grapples with its energy budget.

Protection from Asteroids and Comets

Let's come down to Earth for an issue that has recently shown how astronomy may become relevant to our very survival on this planet. We read in the history of the Jurassic age that huge beasts like dinosaurs used to dominate this planet. What happened to them? What catastrophe wiped them entirely from the face of the earth?

Speculations are many, but one strong possibility is that the earth may have been hit by an extraterrestrial body of appreciable mass, and the impact caused a huge turmoil that wiped out all, or at least most, life forms from the earth. What could such a body be? The space in which the earth moves appears remarkably empty, and so the chance of a collision with another celestial object is indeed very small.

Let us consider a few examples of cosmic collisions. The surface of the Moon is pockmarked with craters, showing evidence that outside bodies have hit it on several occasions. The earth also has such craters, many of which are filled with water and appear as lakes. Some impact craters are confused with volcanic ones. Two examples of craters believed to have formed from impacts are the Meteor Crater in Arizona and the Lonar Crater Lake in the Buldhana district of Maharashtra. As the name of the first one suggests, the impacting body in both cases was a huge meteorite.

Meteorites are bodies orbiting within the solar system, being relatively small bits that did not form into a (much bigger) unit like a planet. Some of them can come close enough to the earth to be attracted by its gravity. In that case, they 'fall' on the earth. Smaller bits of a few centimetres or less are usually burnt out or vaporized by friction as they pass through the atmosphere. They are mistakenly called shooting or falling stars because they shine like stars as they get heated up by the friction of the atmosphere. Some do land on the earth, and if noticed and collected, they end up as museum pieces as well as useful tools for geophysicists. Meteorites have been extremely useful in dating and estimating the age of the solar system, as well as for getting information on its chemical composition.

However, larger meteorites can be devastating in their impact. For example, the meteorite whose impact caused the 'hole' at Lonar is estimated to have measured about 60 metres in diameter and weighed about twenty million tons. The impact created a crater with a diameter of around 1830 metres and a depth of 150 metres. The energy released in the process was equivalent to that coming from a six-megaton H-bomb. For a comparison, 500 atom bombs of the size of the one dropped on Hiroshima equal the impact of the Lonar meteorite. Let's take the Hiroshima case as a unit of energy released, in estimating the magnitudes of impacts by meteorites and other bodies.

Indeed, there are bigger entities than such meteorites going around in the solar system whose impacts we may have to worry about. In July 1994 comet Shoemaker Levy impacted on Jupiter.

The event was witnessed through telescopes on the earth. On the huge planet the impact of a comet had, of course, a transient and relatively mild effect. But what if a comet strikes the earth? Indeed, such a possibility was raised in 1992 in connection with the comet Swift Turtle. This comet passed by at a close but safe distance from the earth. At the time it was predicted that in its next visit on 14 August 2126 it will come very close to the earth. Although it was earlier claimed that the comet would hit the earth, at present this possibility cannot be so confidently asserted. Nevertheless, the probability of its actually hitting the earth is not negligible. A better estimate can only be made when the comet is sighted again in the twenty-second century.

What is now considered more of a threat is an asteroid. Asteroids are a swarm of bodies moving generally in a belt between Mars and Jupiter. It is believed that these represent a 'failed planet', that is, a planet that did not form! These bodies are thus smaller than a planet like the earth, ranging in sizes from several 100 metres to around 10 kilometres, although a few of them are larger, even up to 1000 kilometres in size. These bodies generally lie beyond Mars, but a few of them may occasionally come close to the earth, thus raising the spectre of an impact. It is estimated that the number of asteroids of up to 1 kilometre may be between 1000 and 2000, while the number of 100-metre-sized objects may be as large as 1,00,000. Although the impact of a smaller object is less severe, the chance of its taking place is much larger.

How severe can the impact be? The Lonar example gives some indication. However, suppose a 10-kilometre-sized object hits the earth. What will be the energy released? The answer is a staggering one billion Hiroshimas. Not only will the area hit by the object get devastated, the overall changes in the earth's atmosphere will be such as to make life elsewhere on the planet impossible to sustain. We shall all share the fate of the dinosaurs.

Keeping such possibilities in view, astronomers in the US have initiated the Spacewatch Programme, in which a dedicated 1.8-metre telescope looks for all asteroids of such appreciable sizes in our neighbourhood. With their trajectories charted out, we can predict if any of them will come dangerously close to the earth in the future and take preventive action as needed. This example again tells us that sky gazing is not a mere idle activity: it can contribute to human survival.

Relevance to Indian Science

These are just a few examples of why astronomy is so exciting and worthwhile. But what is its relevance to India? Since astronomy presents frontier-level challenges in fundamental physics *(vide* how the law of gravitation was discovered), let us raise the question as to whether a developing country with limited resources, sorely needed to address many practical problems, can afford fundamental research.

I can do no better than quote the late Dr Homi Bhabha, from the speech he made at the time of dedication of the building of the Tata Institute of Fundamental Research (TIFR) in 1962:

By fundamental research I mean basic investigations into the behaviour and structure of the physical world without any consideration regarding their utility whether the knowledge so acquired would ever be of any practical use. Nevertheless, the support of such research and of an institution where such research can be carried out effectively is of great importance to society for two reasons. First of all, and paradoxically, it has an immediate use in that it helps to train and develop, in a manner in which no other mental discipline can, young men of the highest intellectual calibre in a society into people who can think about and analyse problems with a freshness of outlook and originality which is not generally found. Such men are of the greatest value to society, as experience in the last war showed, for many of the applications of science which were crucial to the outcome of war were developed by men who, before the war, were devoting their time to the pursuit of scientific knowledge for its own sake. Radar and atomic energy are two examples of two fields in which a vast body of known basic knowledge was developed into technology of immense practical importance, largely through the application in war time of the efforts of those who might be called 'pure' scientists.

Secondly, the history of science has shown that 'there is no genuine knowledge of the universe that is not potentially useful for man, not merely in the sense that action may one day be taken on it, but also in the fact that every new knowledge necessarily affects the way in which we hold all the rest of our stock'.[4]

Bhabha was here emphasizing the importance of basic understanding of nature through scientific efforts. Thus, when he set up T1FR in 1946, he concentrated on mathematics, nuclear science and cosmic rays. These apparently unconnected studies do, however, feed upon one another. One can understand the nature of particles coming through cosmic rays if one understands nuclear physics better. Reciprocally, cosmic ray studies provide experimental information that improves our understanding of nuclear physics. And so far as mathematics is concerned, although its practitioners claim that it is an aesthetic pursuit, its results do turn out to be useful to physics as well as to other walks of life.

Bhabha's words are applicable to astronomy as a branch of pure science. As we see today, physics is awaiting a new revolution of ideas, just like it had a century ago, in the form of relativity and quantum theory. Inputs from astronomy may well provide the lead to them. India had once (in the era from Aryabhata to Bhaskara II) held a key position in the world in astronomy and mathematics. It missed out on the Industrial Revolution because the same momentum was not sustained until the eighteenth century. If we are to participate in the march of science and technology that is taking place now, we cannot afford to ignore fundamental research.

So why study astronomy? Because, we want to share in not only the excitement of unravelling more secrets of the universe but also the human enterprise of making our living conditions better.

15. Indian Science Fiction

What is science fiction? There is no unique answer to this question. Hugo Gemsback, after whom the famous Hugo Awards for sci-fi are named, describes it in this way:

By 'scientification', I mean the Jules Verne, H.G. Wells and Edgar Allan Poe type of story—a charming romance intermingled with scientific fact and prophetic vision.

John Campbell, the man who named this type of literature science fiction, had a somewhat broader scope in mind. In his view it was like science in its explanations of known phenomena and predictions of new and undiscovered phenomena but written in story form and applied to machines and people.

More permissive interpretations allow just about anything to be called science fiction, which explains why there is so much trash going under this genre with horror, black magic and fairytales essentially hijacking the true sprit of science fiction. This demeaning feature is reflected in the Indian version also, though to a lesser extent.

In 1897 the famous Bengali scientist Jagadish Chandra Bose wrote one of the earliest Indian sci-fi stories, The Taming of Storm'. Around the same time S.B, Ranade in Maharashtra wrote a Marathi science fiction story called *'Tareche Hasya'* ('Laughter of Tara'). Since then Bengali and Marathi have led the field in Indian science fiction. More recently Satyajit Ray has led the way in writing science fiction in Bengali.

Bal Phondke, a Marathi sci-fi writer, performed an admirable task in 1993 when he brought out It *Happened Tomorrow,* an anthology of sci-fi stories by writers in India.[1] This collection is dominated by stories from Bengali and Marathi, but also represented are stories from Tamil, Kannada, Oriya and Hindi. Phondke points out that the Indianness of Indian sci-fi has more to do with cultural ambience than with the geographical factors because science has no national boundaries. Even though there are some in this country who decry the science done today as Western, there is nothing in the truths discovered by science that has Western cultural values.

Motivating Factors

I have set great store by the science-society interaction as a motivating force for a science fiction story. In India there is a continuing battle between scientific facts and age-old superstitions. Science and technology are seen both as means of curing all existing evils and ailments of the society and as sources of new evils and ailments. Reality lies between the Utopian expectations and doomsday forecasts. Sci-fi can focus on such issues, and the more subtly the message is presented by the fictional component of the story, the greater is its success.

Science fiction stories written with this motivation have a very constructive role to play in India today because our country has been pushed or carried headlong into the age of science, and consequently many misconceptions, fears and antipathies of science exist at all levels of the society. Sci-fi can help make society aware of the power and influence of science and soften any shocks brought about by science-induced social changes. Even if there is no such message, even if it is a futuristic exercise, its setting can still be Indian. Another aspect of such stories is the intermixing of cultures brought about by some worldwide catastrophe wherein the Indianness stands out against the international backdrop.

Good Science Fiction

Can scientists write good science fiction? Certainly with their intimate knowledge of the subject they start with an advantage, but boldness and vision are needed to make it good science fiction. When Fred Hoyle wrote the famous Black *Cloud* in the 1950s, he did so to underscore his expectation that gigantic clouds containing molecules should exist in the vast interstellar space. He had been unsuccessful in convincing his fellow scientists, who felt that nothing more complicated than atoms of hydrogen could exist out there. However, Hoyle's expectation was borne out a decade later when millimetre wave antennas began to detect complex molecules, organic as well as inorganic, in interstellar space. It must have given Hoyle satisfaction to see giant molecular clouds become an established fact of astronomy.

Likewise, when the story of comet Swift Tuttle broke in early 1992, many scientists asserted that on its next trip close to the Sun this comet might hit the earth. If true, this would be a disaster far worse than Hiroshima. If this were to happen, the likely date was predicted as 14 August 2126. Scientists wondered if the collision could be avoided. They said that it was too early to be sure that the collision would take place, but if a head-on collision was going to occur, then it could be averted by deflecting the onrushing comet slightly from its path by exploding a nuclear device in its vicinity. I had envisaged exactly the same scenario and the same solution in my 1976 Marathi story *'Dhoomaketu'* (The Comet'), wherein comet Dutta was shown to be heading for the earth.[3]

'Dhoomaketu' is both scientific and Indian in its themes. In this story, an international task force of scientists plans the secret operation of deflecting the comet, and several yajnas are performed in India to avert the evil. Dutta, an Indian amateur astronomer who discovers the comet, ridicules these superstitions and is proud when the secret multinational operation succeeds. However, when his superstitious wife equally proudly announces that the cometary disaster was averted because of the yajna performed by his grandson, Dutta realizes the chasm existing between science and superstition in the country.

Another story that I wrote in Marathi in the mid-1970s envisaged the possibility that a married couple can predetermine the sex of their next child. It illustrated the adverse impact such a facility could have on the sex-ratio in the Indian society whose mindset is heavily tilted towards the male child. The story ends with the scientist who discovered this method destroying all the documents relating to his discovery. This story was televised on Bombay television and became very popular. It also seemed to have anticipated the future, for a few years later the facility of knowing the sex of a foetus became a reality, and the subsequent alarming numbers of female foeticides made it necessary for the government to ban such diagnosis.

The Respectability Gap

Of the various Indian languages, Marathi and Bengali are presently enjoying the largest following for science fiction. In Marathi, one of the stimuli to would-be writers is provided by the annual competition for the best science fiction short story under the auspices of the Marathi Vidnyan Parishad, Murnbai, a voluntary organization devoted to the popularization of science, largely through the Marathi language. Several of today's established authors have been award winners in this competition. Various periodicals of light literature now solicit science fiction stories, which before 1975 were considered substandard from the standpoint of 'good' literature.

Nevertheless, a respectability gap still exists for sci-fi in the minds of the literati in India. The writer of science fiction is not considered on par with the writer of ordinary short stories or novels. Partly this is the celebrated gap between the two cultures. In India a person opting for a profession in the arts or literature generally has abandoned science long back and therefore feels uncomfortable with any scientific topic. Such a person, therefore, tends to keep away from science fiction, considering it as something beyond comprehension. If the established luminaries of literature become science-friendly and take to writing science-based stories, the literary standard of science fiction in India will definitely improve. Another pleasing consequence will be people's growing familiarity and comfort with science. For the trick lies in portraying science-based events through characters with whom lay readers can identify, and this ability is possessed by all excellent writers of literature.

16. Science and Religion Approach towards a Synthesis

As we enter the third millennium A.D., we need to examine critically the various faiths and creeds that have guided us until now. This is particularly true of Indians, since we live in a country of many faiths. Today's conditions and environment are considerably different from the times when most of these creeds took root. How do they stand up to the present times? What valuable guidance do they have to offer today? Do the many religious traditions that dominate life in India continue to be relevant despite the influx of recent scientific information? While discussing these issues, we must recognize that science has been the main driving force behind many changes in modern society and is likely to continue being so in the foreseeable future. In thinking about creeds for the new millennium, we must consider the relationship between religion and science.

My views arise from the many questions I have in my mind, many of which I cannot answer. As a student of science, I have progressed far enough to realize how little I know about this topic, so I find shelter in a quotation of one of the greatest intellects of the twentieth century. Writing about science and religion in the celebrated scientific journal *Nature,* Albert Einstein admitted,

Science is the century-old endeavour to bring together by means of systematic thought the perceptible phenomena of this world into as thorough-going an association as possible. To put it boldly, it is the attempt at the posterior reconstruction of existence by the process of conceptualization. But when asking myself what religion is, I cannot think of the answer so easily.... I can never in any circumstances bring together, even to a slight extent, all those who have given this question serious consideration.

Einstein's difficulty is felt by most scientists, including me. Why then attempt to bring about a synthesis of views? Such an attempt is worthwhile because, despite the divergence of religious views and different perceptions and methodologies of science and religion, both fields represent human efforts to understand existence and the natural environment that sustains it. If we set aside the mundane details of scientific experimentation and religious rituals and concentrate on the intellectual aspirations on both sides, then there may be considerable common ground for their coexistence.

Einstein was not alone in his views on science and religion. Many great minds have grappled with this theme. While I attempt to tread in their footprints, I am conscious of what Kalidasa, the great Sanskrit poet and dramatist, had to say at the beginning of his *Raghuvansha:*

Being dim-witted but aspiring for the success of the learned, I will end up in ridicule, like a dwarf raising his hands towards a fruit that can be reached only by a tall person.'

Raghuvansha 1.3

But having written these lines, Kalidasa went on to produce a masterpiece. While I subscribe to Kalidasa's sentiments, I hold out no such hope for myself.

Man and the Universe

Let's begin by reviewing our present understanding of the cosmos, an understanding that has grown considerably over the last few decades but which cannot be considered in any way complete. I do so because the subject of cosmology, which deals with the origin and evolution of the universe, tells us how small man is, how limited his experience on this tiny planet is in comparison with the physical universe that he can observe.

Here on the earth we are dependent on the Sun to give us energy to sustain life. The brightest object in the sky, the Sun is fortunately reasonably far away from us (some hundred and fifty million kilometres—as much as light covers in about five hundred seconds) so that we are spared the enormous heat it generates. But astronomy teaches us that the Sun is literally at our doorsteps compared to the stars we see in the night sky. The nearest of them, Proxima Centauri, is located about four and a quarter light years from us. That is, light from Proxima Centauri takes four and a quarter years to reach us, far more than the five hundred seconds taken by sunlight. No wonder that the stars viewed from such vast distances look so faint. In fact, in the stellar world, the Sun can boast of no particular distinction! It is neither the brightest nor the biggest star. It is very ordinary, so far as luminosity and size go.

These stars that we see are but a very tiny fraction of the more than hundred billion that reside the Milky Way. The Milky Way itself is like a disc with a diameter of a hundred thousand light years. Until the early part of this century, the human ego generated a firm belief that our galaxy is the only object in the universe; that is, everything that the astronomer discovered through his telescopes was believed to belong to the Milky Way.

This belief was rudely shattered in the 1920s with the realization that many of the faint nebulous patches appearing on astronomical photographs were galaxies in their own right, of a size comparable to the Milky Way and at distances of millions of light years. Today telescopes like the Hubble Space Telescope or the large ground-based telescopes like the Keck telescopes are showing us a universe even grander than ours. It is made of clusters of galaxies grouped in large superclusters hundred million light years across or even larger, separated by giant voids, with the entire structure expanding in a very systematic way. Looking as far as ten billion light years, these telescopes continue to see no end to the spread of the universe.

What caused the expansion of the universe? How did galaxies come together in their clusters and superclusters? Indeed, how did panicles that comprise basic constituents of matter first form? We see the universe bathed in a radiation background of very low temperature. What was its origin due to? These are questions posed by today's cosmologists. They are different from those asked by scientists of yesteryears, of even one hundred years ago when astronomy hardly reached beyond the confines of the Milky Way. Have we reached the end of the quest, or does something lie beyond our Galaxy?

These questions and the enormity of the universe in comparison with the human habitat here on the earth have had a humbling influence on some of the greatest scientific brains of this century. Let's consider a couple.

'Man in his search for knowledge of the universe is like a potato bug in a potato in the hold of a ship trying to fathom from the ship's motion the nature of the vast sea,' said British cosmologist and Plumian Professor at Cambridge Arthur Stanley Eddington in one of his pubic lectures. He said this as cosmology was developing with the 1929 discovery by Hubble that the universe is expanding. Forty years later Fred Hoyle, another astronomer who held the same professorship, stated,

I think it is very unlikely that a creature evolving on this planet, the human being is likely to possess a brain that is fully capable of understanding physics in its totality. I think this is inherently improbable in the first place, but even if it should be so, it is surely wildly improbable that this situation should just have been reached in the year 1970.

I have given these details to establish a frame of reference. Perhaps I should also say something about my local environment and heritage, which directly or indirectly have influenced my thinking. I come from Maharashtra, which recently celebrated the seventh centenary of Sant Jnaneshwara (1275-96), whose works have continued to influence and guide people through their practical and pragmatic philosophy. In his works, Jnaneshwara had emphasized tolerance among the many approaches in search of the universal truth. In the seven hundred years since, science has made remarkable progress. Its powers, both benign and destructive, are abundantly clear today as are its numerous influences on society. Many therefore see it as a challenger to established religions.

Common Goals

Here I wish to highlight aspects of the science versus religion debate from my own somewhat narrow but pragmatic vantage point. Both science and religion are guided by man's search for the truth, yet their approaches are different. Even their concepts of what they mean by truth are different.

Science took shape out of man's curiosity about nature, about the various natural events going on around him, about the Sun, the Moon and the stars and planets, about lightning and thunder, about the living things great and small and about the origin of the universe. Although it took several centuries for the scientific method to get established, once it did take shape, it spread fast. Experiment, observation, theory and predictions formed its basis. From a certain level of understanding of nature, scientists ask further questions. From their efforts to find answers, they advance to a higher level and new questions await them, ones which they could not have even thought of earlier given their lower level of understanding.

Planet, star, galaxy, cluster, supercluster—at each level of the large-scale structure in the universe, the scientific establishment resisted this ascent in the hierarchy. A minority argued for the next stage in the ladder but were overruled. However, in the last analysis, the minority view was vindicated as scientific decisions are ultimately determined by facts, not by a majority vote.

And so science goes on expanding its knowledge base and looking for facts at more sophisticated levels. The process is seemingly an endless one. But so far it seems unable to grapple with questions relating to the workings of the human mind, its feelings, emotions and the urge to know. Why is man created? Why are so many living species of different sorts in existence? What is the purpose of this creation? Why are there laws of science in the first place? Why do the laws discovered by man on this tiny Earth seem to work on the much grander scales of stars and galaxies?

These questions about the cosmic truth seem beyond the scope of science. This is where religion steps in. Different religions have provided different thought structures to answer such questions. Even the role of the Creator, or God, assumes different proportions in different contexts. There are hierarchies in attempts to attain knowledge via religion too. In the Gita, for example, Krishna tells Arjuna

Better indeed is knowledge than the practice (of concentration), better than knowledge is meditation; better than meditation is renunciation of the fruit of action; on renunciation (follows) immediate peace.

Gita 12.2

In all religions there is an ultimate state of perfection that the individual may aspire to. This may be Moksha, Nirvana, the Paradise or some other form. This state is one where basically all questions are answered.

In a sense, science would also like to reach that state, but it is very unlikely that it ever will. Indeed, in contrast to the religious seeker who attains peace and contentment at the conclusion of his search with the above goal, scientists may find the universe a very dull and boring place to live in once all their questions have been answered.

Different Approaches

The scientific truth, however, is very different from the religious one, even when both are incomplete. Science insists on objectivity, on the repeatability of its experiments, on their validity on a universal scale. Thus if the claims of scientist X cannot be experimentally or observationally confirmed by scientist Y, scientist Z, etc., they are viewed with scepticism. If Galileo found that the speed of a stone dropped from the Leaning Tower of Pisa grew in proportion to time after drop, the same result would have to be obtained by any Tom, Dick or Harry performing the same experiment.

But with religious experiences it is a different story. When Krishna showed Arjuna his Universal Form he told him:

Neither by the Vedas, (nor by) sacrifices nor by study nor by gifts nor by ceremonial rites nor by severe austerities can I with this form be seen in the world of men by-anyone else but thee, O hero of the Kurus (Arjuna).

Gita 11.48

Thus only Arjuna had been privileged to see the Universal Form. No scientist can similarly get away by saying, ‘Only I have seen the proton decay. Others cannot see it happen.’

This is the main contrast between science and religion, in their perception of truth: the objectivity insisted on by the scientist versus the highly subjective personal experiences of the religious. Conflicts arise when scientists are asked to believe these unique experiences of the select few. They obviously will not believe what they cannot themselves observe or experience. On the other hand, a deeply religious follower of a seer who has had that experience sincerely believes that the experience is real. Indeed, he may consider scientists obdurate in their disbelief.

Secondly, scientists, aware of the partial truths they have established, know the difficulty of reaching the goal of complete knowledge. Most religions tell them, on the other hand, that they (the religions) have the complete knowledge—again based on the experiences of the select few. Scientists are uncomfortable with the tone of authority of such a claim. These differences are genuine and must be appreciated and respected on both sides. There are, however, other issues that complicate the matter further.

Most religions of the world started off as or evolved into moral codes of conduct, which are essential for a collection of human beings to live together as a society. Thus there are inevitably several dos and don'ts. For example, there are the Ten Commandments. Moreover, religions further evolved methods of providing peace to the human mind. These methods in turn shaped human thinking.

Nevertheless, problems arose when these sincere and practical instructions got mixed up with rituals, so much so that the latter eventually superseded the former. At some stage, especially in India, astrology also got into the game with the 'evil planets' having to be propitiated. Then there were the performances of claimed miracles, which continue to this day. Like a teacher who cannot establish his credentials through wisdom but must resort to tricks to command his students' respect, so must charlatans rely on so-called miracles to influence their devotees. When these miracles of modern times are debunked by scientific scrutiny, when astrological predictive apparatus is demonstrated to be ineffective and unscientific, it is not surprising that scientists show antipathy for religion and regard it as no more than a vehicle for superstitions.

Just as these pseudo-religious practices bring a bad name to religion, so does fanaticism which today goes under the name of fundamentalism. Fundamentalism precludes any questioning of the tenets, and hence it is totally contrary to the scientific outlook. Moreover, religious fundamentalism finds scientific facts unpalatable and therefore resists them and even science itself.

Having passed these critical remarks on the present religious ambience, let me hasten to add that the slate is not clean on the scientific side either. It is a measure of the social pressures on scientists that one notices a dimming of the objectivity that is the hallmark of science and sees the emergence of scientific fundamentalism. Copernicus and Galileo suffered from this fundamentalism when they proposed the heliocentric theory as an alternative to the geocentric theory. One could complacently argue that the fundamentalism they encountered was of a religious nature. This argument is only partly true because intellectuals not belonging to the Catholic clergy, like Martin Luther, opposed the heliocentric theory. One may say that for fear of losing prestige and secure positions, the intellectuals of the sixteenth and the early seventeenth centuries were reluctant to take public positions in favour of the heliocentric theory. Let us now see the compulsions that drive present-day science.

A comment on sociology illustrates how today's science progresses. Supposing you have been promoting a very popular theory. Any research work today requires a lot of money, and the money for it usually comes from the government coffers. So you have to make a proposal for funding your research, and if you have established credibility already, then reviewers of your proposal will say that this is a safe kind of proposal and recommend funding it. But if you send a proposal questioning some of the established doctrines, then the peer reviewers would say that this is a very contentious proposal; we do not know what will come out of it, so let us not waste money on it.

A proposal that Geoffrey Burbidge once sent to the National Science Foundation for work on quasi-steady state cosmology (which questions the commonly accepted paradigm that the universe was created in a Big Bang) was turned down by one referee on the grounds that no research student or postdoctoral student should be allowed to work on such a scatterbrained idea. Another referee wrote that the idea must be an unsafe and scatterbrained one because there are no postdoctoral or research students working on it. So there you run into a vicious circle! How will you get research and postdoctoral students working on it unless you have the proposal funded? Such a 'cautious' attitude will naturally kill any challenges to a commonly held belief.

In a millennium essay in Nature, I cited an episode that I had heard from the late Professor Chandrasekhar. He mentioned that when a decision was taken to fund the 200-inch telescope at Mount Palomar in the late 1930s, there was a press conference in which both Hubble and Eddington were present. They were asked: 'Sir, if you build this telescope what do you expect to find with it?' They replied that if you knew the answer to this question beforehand there would be no purpose in building it. It was a perfectly legitimate and open-minded answer. But today if you make a proposal for building a telescope you have to give a detailed reasoning stating what you expect to find with that telescope. That means you already have made up your mind what you are going to find, and that is based on what you already believe in. So you are not going to discover anything new except by sheer fluke.

This is a very unfortunate direction in which basic science like astronomy is currently heading. Because a lot of money is involved, scientists like to play it safe, so today there is no such thing as venture funding in science. I made a case that there should be a certain fraction of the money available for venture ideas. Howsoever crazy we may think it is, if the proposer has established credibility, if he has done good work in the past and is now saying that we should explore a new avenue, we should support the project. I feel that that is the only way we can rescue science from being bogged down into a completely conformist exercise.

In this context, the Indian situation seems more promising than in the West. In India there is also a peer review system, but it is not as rigid and critical as the West's. This is sometimes cited as symptomatic of weakness; but it can also be a source of strength. For some venture projects that would be considered unworkable in the West would be allowed under the Indian system. Certainly a Chip Arp would have less problems finding observing time on Indian telescopes. Thus I would say that a new idea stands a better chance of being tried in India than in the West. R.A. Mashelkar, the present director-general of the Council of Scientific and Industrial Research, took the bold step of introducing a venture fund for testing and trying new ideas and projects. It has generated fresh work, whose efficiency will be seen in time. In the last analysis, willingness to try out new ideas is an indication of confidence, while tendency to suppress alternatives suggests a feeling of insecurity.

Perhaps carried away by conformism, many distinguished scientists often delude themselves that their tried and proven path represents the real and ultimate facts about the universe; they do so to the extent that they believe that the end of their quest is near. In fact the reverse is true: A feeling of complacency is an indication that the tried and proven method has reached the end of its usefulness and something very different is needed. Towards the end of the nineteenth century, the rapid advances of gravitation theory, electromagnetic theory and thermodynamics led many scientists to believe that the end of physics had been reached. These prophesies were belied by two major revolutions of the twentieth century, namely, the theory of relativity and the quantum theory. Both these inputs came during the first two decades of that century. It is interesting to see history repeat itself with a scientist of the stature of Stephen Hawking saying in 1980 that the end of physics is round the corner. That comer already seems to be receding. Thus, given these departures from the cherished image of science, the discerning layman is justified in questioning the infallibility of science and the wisdom of putting all one's intellectual eggs in the scientific basket.

The Concept of God

Scientists are often asked if they believe in God. This question is not so simple as it sounds for the notion of God is so variable from person to person that any simple answer can be grossly misleading. Is the scientist expected to prove the existence of God by demonstrating how well ordered the working of the universe *is?* Does the assumption that God exists help him understand why there are laws of science? Judged purely by scientific logic, a fresh postulate that simply justifies only what is already known is no advance in one understands. In other words, I find that putting this question to a scientist (because he is a scientist) is unfair.

Questions about why the universe is governed by laws of science, or what agency decided that these and no other laws shall operate are beyond the scope of science. Simply postulating God to answer these questions does not take us very far. But the basic faith scientists have—the one that keeps them in business-is that there are some basic laws governing nature and the declared aim of science is to find them.

Replies from scientists may differ, thus indicating that the question of whether there is a God cannot be answered in objective terms, like whether they believe in dark matter. Einstein addressed the issue in this way:

During the youthful period of mankind's spiritual evolution, human fantasy created gods in man's own image, who, by the operations of their will, were supposed to determine, or at any rate to influence, the phenomenal world. Man sought to alter the disposition of these gods in his own favour by means of magic and prayer. The idea of gods in the religions taught at present is a sublimation of that old conception of gods. Its anthropomorphic character is shown, for example, by the fact that men appeal to the Divine Being in prayers and plead for the fulfilment of their wishes.

Here Einstein is expressing his negation of a personal God who intervenes in people's lives to solve their problems or mete out punishment for transgressions. Such interventions would bring God down to the level of humans and raise fresh contradictions.

Imagine the following everyday situation. College student A does not study regularly, and as an examination approaches, he realizes that he cannot get the high percentage of marks that he needs for his future career. So A goes to a temple or a mazar and makes an offering to the diety or pir. Student B, in a similar predicament, is more down to earth. He discovers who the examiners are and bribes them. A third student, C, on the other hand, has been working hard and conscientiously throughout the year and is confident of scoring high marks. Are the expectations of A about the morality of his God any different from those of B with respect to the examiners? If God or the Pir indeed fulfils the prayers of A, does God or Pir not come down to the level of the bribed examiners, and is student C not treated unfairly in the whole exercise?

Einstein had objections to a God of this kind. He urged,

In their struggle for the ethical good, teachers of religion must have the stature to give up the doctrine of a personal God, that is, give up that source of fear and hope which in the past placed such vast power in the hands of priests.

Instead, he hoped that religions would aid science as it searches further for the truth behind the regularity of the universe, from the very microscopic level to the grandest level. A great deal remains to be learnt to understand the mystery behind the observed rationality of the operations of nature.

These examples illustrate, but by no means exhaust, the differing perspectives on the question. So when someone asks if I, a scientist, believe in God, I reply that the question is too difficult for me to answer, and even if I tried, my answer might be misleading, for the listener will interpret my reply within his perception of God, which may be totally different to mine.

Complementarities and Synthesis

Given these difficulties that separate the real from the ideal, what can we do to bridge the gap? It is necessary to recognize that religion and science fulfil complementary urges of the human mind. The problems come when there is a trespass of the area of either one by the other. Thus scientists should avoid passing value judgements on religious thoughts without appreciating their very different contexts, and religious thinkers should not try to look for post facto justification of their thoughts in the findings of science.

To achieve a synthesis or at least a coexistence of science and religion, several steps are possible. First, the religions can be pragmatic enough to adapt their philosophies to the new facts of the universe, large and small, revealed by science. Religious concepts and beliefs must be consistent with the scientific facts. Scientists, on the other hand, must be always aware -of the incompleteness of their knowledge and hence receptive to new ideas and concepts. As they further their understanding of the operations of the human brain, their researches may very well add to the philosopher's thoughts on reality, consciousness and the purpose of existence. Thus scientists should constantly remind themselves that there are at least a few concepts and experiences that their laws do not reach today and perhaps may never reach. In short, science and religion have much to gain by being pragmatic, by learning from each other. In this context I am reminded of the oft-quoted line from the *Ishavasyopanishad:*

Avidyaya mrutyum teertwa vidyayamrutamashnute

I do not pretend to be a Vedic scholar, when I interpret this line as saying that *avidya* (acts and deeds) can be used to transcend death and *vidya* (spiritual knowledge) can help to digest the nectar of supreme happiness. Science as part of the former has come to regulate our lives and how we act; it needs to be supplemented by the latter, which should come from our creeds.

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