The wonder that was India: Excerpts from Dharampal's book *Indian Science and Technology in the 18th Century* (1971)

By

K. Kesava Rao

Department of Chemical Engineering

Indian Institute of Science

Bengaluru 560012, India

kesava@iisc.ac.in

INTRODUCTION:

This article consists of excerpts taken from the above book, which was edited by Dharampal (1971). The book contains accounts by Europeans who visited India in the late eighteenth and early nineteenth centuries.

It is astonishing to learn from these accounts that our ancestors could apparently predict the motions of the planets (well before the advent of Newtonian mechanics). They had a good estimate of π ($\approx$ 3927/1250 = 3.1416), and were aware of the binomial coefficients for integral values of the exponent (several centuries before the general case was stated without proof by Newton in 1676). They also constructed solutions of certain algebraic equations several centuries before these solutions were reinvented in France and England.

They were adept at inoculating people against small-pox (over 100 years before the introduction of inoculation in Britain); they could make ice by exploiting radiative transfer from pans of water exposed to the atmosphere; they had a sound knowledge of agriculture practices; could make steel bars of good quality (without foreign collaboration); and could perform plastic surgery.

These topics are described in the excerpts given below. Supplementary remarks have been added at a few places. These are enclosed by square brackets.

Excerpts

1. Astronomy

1.1. Bramin's observatory at Benares (Barker, 1777)

We entered this building, and went up a stair-case to the top of a part of it, near to the river Ganges, that led to a large terrace, where, to my surprize and satisfaction, I saw a number of instruments yet remaining, in the greatest preservation, stupendously large, immovable from the spot and built of stone, some of them being upwards of 20 feet in height; and although they are said to have been erected 200 years ago, the graduations, and divisions on the several arcs appeared as well cut, and as accurately divided, as if they had been the performance of a modern artist. The execution in the construction of this instrument exhibited a mathematical exactness in the fixing, bearing, and fitting of the several parts, in the necessary and sufficient support to the very large stones that composed them and in the joining and fastening each into the other by means of lead and iron.

The situation of the two large quadrants of the instrument marked A in Fig.1 whose radius is nine feet two inches, by there being yet right angles with a gnomon at twenty five degrees elevation, are grown into such an oblique situation as to render them the most difficult, not only to construct of such a magnitude, but to secure in their position for so long a period, and afford a striking instance of the ability of the architect in their construction; for, by the shadow of the gnomon thrown on the quadrants, they do not appear to have altered in the least from their original position; and so true is the line of the gnomon, that, by applying the eye to a small iron ring of half-an-inch diameter at one end, the sight is carried through three others of the same dimension to the extremity at the other end, distant thirty-eight feet, eight inches, without obstruction; such is the firmness and art with which this instrument has been executed. This performance is the more wonderful and extraordinary when compared with the works of the artificers of Hindustan at this day, who are not under the immediate direction of an European mechanic; but arts appear to have declined equally with science in the east.

Lieutenant-colonel Archibald Campbell, at that time chief engineer in the East India Company's service at Bengal, a gentleman whose abilities do honour to his profession, made a perspective drawing of the whole of apparatus that could be brought within his eye at one view; but I lament he could not represent some very large quadrants, whose radii were about twenty feet, they being on the side from whence he took this drawing. Their descriptions however is, that they are exact quarters of circles of different radii, the largest of which I judged to be twenty feet, constructed very exactly on the sides of stone walls built perpendicular, and situated, I suppose, in the meridian of the place: a brass pin is fixed at the centre or angle of the quadrant, from whence, the Bramin informed me, they stretched a wire to the circumference when an observation was to be made; from which it occurred to me, the observer must have moved his eye up or down the circumference, by means of a ladder or some such contrivance, to rise and lower himself, until he had discovered the altitude of any of the heavenly bodies in their passage over the meridian, so expressed on the arcs of these quadrants; these arcs were very exactly divided into nine large sections; each of which again into ten, making ninety lesser divisions or degrees: and those also into twenty, expressing three minutes each, of about two-tenths of-an inch asunder; so that it is probable, they had some method of dividing even these into more minute divisions at the time of observation.

My time would only permit me to take down the particular dimensions of the most capital instrument, or the greater equinoctial Sun-dial; represented by A (Fig. 1), which appears to be an instrument to express solar time by the shadow of a gnomon upon two quadrants, one situated to the east, and the other to the west of it; and indeed the chief part of their instruments at this place appear to be constructed for the same purpose, except the quadrants, and a brass instrument that will be described hereafter.

The sketch labelled B in Fig. 1 is another instrument for the purpose of determining the exact hour of the day by the shadow of a gnomon, which stands perpendicular to and in the centre of a flat circular stone, supported in an oblique situation by means of four upright stones and a cross-piece; so that the shadow of the gnomon, which is a perpendicular iron rod, is thrown upon the divisions of the circle described on the face of the flat, circular stone
The sketch labelled C in Fig. 1 is a brass circle, about 2 feet in diameter, moving vertically upon two pivots between two stone pillars, having an index or hand turning round horizontally on the centre of the circle, which is divided into 360 parts; but there are no counter divisions on the index to sub-divide those on the circle. This instrument appears to be made for taking the angle of a star yet setting or rising or for taking the azimuth or amplitude of the Sun yet rising or setting.

The use of the instrument (the sketch labelled D in Fig. 1), I was at a loss to account for. It consists of two circular walls; the outer of which is about 40 feet diameter, and 8feet high; the wall within about half that height, and appear intended for a place to stand on to observe the divisions on the upper circle of the outer wall, rather than for any other purpose; and yet both circles are divided into 360 degrees, each degree being-divided into 20 lesser divisions, the same as the quadrants. There is a door way to pass into the inner circle and a pillar in the centre, of the same height with the lower circle, having a hole in it, being the centre of both circles and seems to be a socket for an iron rod to be placed perpendicular into it. The divisions on this, as well as all the other instruments, will bear a nice examination with a pair of compass.

Figure E is a smaller equinoctial Sun-dial, constructed upon the same principle as the large one A.

I cannot quit this subject without observing that the Bramins without the assistance of the optical glasses had nevertheless an advantage inexperienced by the observers of the more Northern climax. The serenity and the clearness of the atmosphere in the night-time in the East Indies, except at the seasons of the changing the monsoon or periodical winds, is difficult to express to those who have not seen it, because we have nothing in comparison to form our ideas upon: it is clear to perfection, a total quietude subsists, scarcely a cloud to be seen; and the light of the heaven, by the numerous appearance of the stars, afford a prospect both of wonder and contemplation.

This observatory at Benares is said to have been built by the order of the Emperor Ackbar; for as this wise prince endeavoured to improve the arts, so he wished also to recover the sciences of Hindostan, and therefore directed that these such places should be erected; one at Delhi, another at Agra and third at Benares.

Some doubts have arisen with regard to the certainty of the ancient Brahmins having a knowledge in astronomy, and whether the Persians might not have introduced it into Hindostan, when conquered by that people; but these doubts I think must vanish when we know that the present Bramins announce, from the records and tables which have been handed down to them by their forefathers, the approach of the eclipses of the Sun and Moon, and regularly as they advance give timely information to the emperor and the princes in whose dominion they reside. There are yet some remains in evidence of their being at one time in possession of this science. The signs of the Zodiac, in some of their Choultrys on the coast of Coromandel [the East coast], as remarked by John Call, Esq. F.R.S. in his letter to the Astronomer Royal, requires little other confirmation. Mr. Call says, that as he was laying on his back, resting himself in the heat of the day, in a choultry at Verdapetah in the Madura country, near Cape Commorin [Kanyakumari], he discovered the signs of the Zodiac on the ceiling of the choultry: that he found one, equally complete, which was on the ceiling of a temple, in the middle of a tank before the pagoda Teppecolam near Mindurah; and that he had often met with several parts in detached pieces. (See Philos. Trans 1772, p.353). These buildings and temples were the places of residence and worship of the original Brahmins, and bear the marks of great antiquity, having perhaps been built before the Persian conquest. Besides, when we know that the manners and customs of the Gentoo religion are such as to preclude them from admitting the smallest innovation in their institutions; when we also know that their fashion in dress, and the mode of their living have not received the least variation from the earliest account you have of them; it cannot be supposed they would engrave the symbolical figures of the Persian astronomy in their sacred temple, the signs of the Zodiac must therefore have originated; with them, if we credit their tradition of the purity of their religion and customs.

1.2. Remarks on the astronomy of the Brahmin's (Playfair 1790)

The tables, and methods, of the Brahmin's of Tirvalore, are, in many respects more singular than any that have yet been described. (Tirvalore is a small town on the Coromandel coast, about 12G miles west of Negapatnam, in Lat. 10 degrees, 44 minutes. and east Long, from Greenwich 79 degrees, 42 minutes, by Rennell's map.)

These tables go far back into antiquity. Their epoch coincides with the famous era of the Calyougham, that is with the beginning of the year 3102 before Christ. (In order to calculate for a given time, the place of any of the celestial bodies, three things are requisite. The first is, the point of the body in some past instant of time, ascertained by observation; and this instant, from which every calculation must set out, is usually called the *epoch* of the tables.) When the Brahmins of Tirvalore would calculate the place of the Sun for a given time, they begin by reducing into days the interval between the time, and the commencement of Calyougham, multiplying the years by 365 days, 6 hours, 12 minutes, 30 seconds; and taking away 2 days, 3 hours, 32 minutes, 30 seconds, the astronomical epoch having begun that much later than the civil. They next find, by means of certain divisions, when the year current began, or how many days have elapsed since the beginning of it, and then, by the table of the duration of the months, they reduce these days into astronomical months, days, etc. which is the same with the signs, degrees and minutes of the Sun's longitude from the beginning of the zodiac. The Sun's longitude, therefore, is found.

The tables of Tirvalore, however, though they differ in form very much from those formerly described, agree with them perfectly in many of their elements. They suppose the same length of the year, the same mean motions, and the same inequalities of the Sun and Moon and they are adapted nearly to the same meridian. But a circumstance in which they seem to differ materially from the rest is, the antiquity of the epoch from which they take their date, the year 3102 before the Christian era. We must, therefore, enquire, whether this epoch is real or fictitious, that is, whether it has been determined by actual observation, or has been calculated from the modern epochs of the other tables.. For it may naturally be supposed, that the Brahmins having made observations in later times or having borrowed from the astronomical knowledge of other nations, have imagined to themselves a fictitious epoch, coinciding with the celebrated era of the Calyougham, to which through vanity or superstition, they have referred the places of the heavenly bodies and have only calculated what they pretend that their ancestors observed.

In doing this, however, the Brahmins must have furnished us with means, almost infallible, of detaching their imposture. It is only for astronomy, in its most perfect state, to go back to the distance of forty-six centuries and unto ascertain the situation of the heavenly body yet so remote a period. The modern astronomy of Europe, with all the accuracy that it derives from the telescope and the pendulum could not venture on so difficult a task, were it not assisted by the theory of gravitation, and had not the integral calculus, after a100 years of almost continual improvement, been able, at last, to determine the disturbances in our system, which arise from the action of the planets on one another.

Unless the corrections for these disturbances be taken into account, any system of astronomical tables, however accurate at the time of its formation, and however diligently copied from the heavens, will be found less exact for every instant, either before or after that time, and will continually diverge more and more from the truth, both for future and past ages. Indeed, this will happen not only from the neglect of these corrections, but also from small errors unavoidably committed in determining the main motions, which must accumulate with time and produce an effect that becomes every day more sensible, as we retire, on either side, from the instant of observation. For both reasons it may be established as a maxim, that if there be given a system of astronomical tables, founded on observations of an unknown date, that date may be found, by taking the time when the tables represent the celestial motions most exactly.

The moon's mean place for the beginning of the Calyougham (that is, for midnight between the 17th and 18th of February 3102, B.C. at Benaras), calculated from Mayer's tables, on the supposition that her motion has always been at the same rate as at the beginning of the present century, is 10^{s}, 0 degrees, 51 minutes, 16 seconds. But, according to the same astronomer, the moon is subjected to a small, but uniform acceleration, such, that her angular motion, in any one age, is nine seconds greater than in the preceding, which, in an interval of 4801 years, must have amounted to 5 degrees, 45 minutes, 44 seconds. This must be added to the preceding, to give the real mean place of the moon, at the astronomical epoch of the Calyougham, which is therefore 10 seconds, 6 degrees, 37 minutes. Now, the same, by the Tables of Tirvalore, is 10^{s}, 6 degrees, 0 minutes; the difference is less than two thirds of a degree, which for so remote a period, and considering that acceleration of the moon's motion for which no allowance could be made in an Indian calculation, is a degree of accuracy that nothing but actual; observation could have produced.

Thus have we enumerated no less than nine astronomical elements (the inequality of the precession of the equinoxes; the acceleration of the moon; the length of the solar year; the equation of the sun's centre; the obliquity of the ecliptic; the place of Jupiter's aphelion; the equation of Saturn's centre; and the inequalities in the main motion of both these planets) to which the tables of India assigns such values as do, by no means, belong to them in these later ages, but such as the theory of gravity proves to have belonged to them three thousand years before the Christian era. At that time, therefore, or in the ages preceding it, the observations must have been made from which these elements were deduced. For it is abundantly evident, that the Brahmins of later times, however, willing they might be to adapt their tables to so remarkable an epoch as the Calyougham, could never think of doing so, by substituting, instead of quantities which they had observed, others which they had no reason to believe had ever existed. The elements in question are precisely what these astronomers must have supposed invariable, and of which, had they supposed them to change, they had no rules to go by for ascertaining the variations; since, to the discovery of these rules is required, not only all the perfection to which astronomy is, at this day, brought in Europe, but all that which the sciences of motion and of extension have likewise attained. It is no less clear, that these coincidences are not the work of accident; for it will scarcely be supposed that chance has adjusted the errors of the Indian astronomy with such singular felicity, that observers, who could not discover the true state of heavens, at the age in which they lived, have succeeded in describing one which took place several thousand years before they were born.

In another part of the calculation of eclipses, a direct application is made of one of the most remarkable propositions in geometry. In order to have the semiduration of a solar eclipse, they subtract from the square of the sum of the semi-diameters of the sun and moon, the square of a certain line, which is a perpendicular from the centre of the sun on the path of the moon; and from the reminder, they extract the square root, which is the measure of the semiduration. The same thing is practised in lunar eclipses. These operations are all founded on a very distinct conception of what happens in the case of an eclipse, and on a knowledge of this theorem, that in a right-angled triangle, the square of the hypotenuse is equal to the squares of the other two sides. It is curious to find the theorem of Pythagoras in India, where, for aught we know, it may have been discovered, and from whence that philosopher may have derived some of the solid, as well as visionary speculations, with which he delighted to instruct or amuse his disciples.

The preceding calculations must have required the assistance of many subsidiary tables, of which no trace has yet been found in India. Besides many other geometrical propositions, some of them also involve the ratio which the diameter of a circle was supposed to bear to its circumference, but which we would find it impossible to discover from them exactly, on account of small quantities that may have been neglected in their calculations. Fortunately, we can arrive at this knowledge, which is very material when the progress of geometry is to be estimated, from a passage in the *Ayeen Akbary*, where we are told, that the Hindoos suppose the diameter of a circle to be to its circumference as 1250 to 3927, and where the author, who knew that this was more accurate than the proportion of Archimedes (7 to 22), and believed it to be perfectly exact, expresses his astonishment, that among so simple a people, there should be found a truth, which, among the wisest and most learned nations, had been sought for in vain.

The proportion of 1250 to 3927 is indeed a near approach to the quadrature of the circle; it differs little from that of Metius, 113 to 355, and is the same with one equally remarkable that of 1 to 3.1416. When found in the simplest and most elementary way, it requires a polygon of 768 size to be inscribed in a circle; an operation which cannot be automatically performed without the knowledge of some very curious properties of that curve, and, at least, nine extractions of the square root, each as far as ten places of decimals. All this must have been accomplished in India; for it is to be observed, that the above mentioned proportion cannot have been received from the mathematicians of the West. The Greeks left nothing on this subject more accurate than the theorem of Archimedes; and the Arabian mathematicians seem not to have attempted any nearer approximation. The geometry of modern Europe can much less be regarded as the source of this knowledge. Metius and Vieta (1540-1603 AD) were the first, who, in the quadrature of the circle, surpassed the accuracy of Archimedes; and they flourished at the very time when the Institutes of Akbar were collected to India.

On the grounds which have been explained, the following general conclusions appear to be established.

1. The observations, on which the astronomy of India is founded, were made more than 3000 years before the Christian era; and, in particular, the places of the Sun and Moon at the beginning of the Calyougham, were determined by actual observation.

This follows from the exact agreement of the radical places in the tables of Tirvalore, with those deduced for the same epoch from the tables of De La Caille and Mayer, and especially in the case of the moon, when regard is had to her acceleration.

Of such high antiquity, therefore, must we suppose the origin of this astronomy, unless we can believe, that all the coincidences which have been enumerated, are but the effects of chance or what is still more wonderful, that, some ages ago, there had arisen a Newton among the Brahmins, to discover that universal principle which connects not only the most distant regions of space, but the most remote periods of duration; and a De La Grange, to trace, through the immensity of both its most subtle and complicated operations.

[Dharampal notes that “the widespread prevalence of European ethnocentric bias” comes through in the above review by J. Playfair, professor of mathematics at the University of Edinburgh: “It became intellectually easier for him to concede this astronomy’s antiquity rather than its sophistication and the scientific capacities of its underlying theories.”]

2. **Algebra (**Burrow, 1790)

I mean very shortly to publish translations of the *Leelvatty* and *Beej Ganeta*, or the Arithmetic and Algebra of the Hindoos. [As noted by Burton (1985), the *Lilavati* and the *Vijagnita* form the first two parts of Bhaskara’s book *Siddhanta Siromani*. The book was written in 1150 A.D. and translated into Arabic in 1587 A.D.] With respect to the binomial theorem, the application of it to fractional indices will perhaps remain forever the exclusive property of Newton; but the following question and its solution shows that the Hindoos understood it in whole numbers to the full as well as Briggs, and much better than Pascal. [Briggs (1561-1630) was an English mathematician who invented the logarithm to the base 10. Pascal (1623-1662) was a French mathematician, physicist, and philosopher. He developed ‘Pascal’s triangle’, which displays the binomial coefficients.]

A Raja’s palace had eight doors; now these doors may either be opened by one at a time; or by two at a time; or by three at a time; and so on through the whole, till at last all are opened together. It is required to tell the numbers of times that this can be done.

Set down the number of the doors, and proceed in order to gradually decreasing by one to unity and then in a contrary order as follows:

8 7 6 5 4 3 2 1

1 2 3 4 5 6 7 8

Divide the first eight by the unit beneath it, and the quotient eight shows the number of times that the doors can be opened by one at a time: multiply this eight by the next term seven, and divide the product by the two beneath it, and the result twenty-eight is the number of times that two doors may be opened; multiply the last found twenty-eight by the next figure six, and divide the product by the number three beneath it, and the quotient of fifty-six shows the number of times that three different doors may be opened: again this fifty-six multiplied by the next number five and divided by the four beneath it, is seventy, the number of times that four different doors may be opened: in the same manner fifty-six is the number of fives that can be opened: twenty-eight the number of times that six can be opened: eight the number of times that seven can be opened and lastly, one is the number of times the whole may be opened together, and the sum of all the different times is 255.

3. Medicine

3.1 Operation of inoculation of the smallpox as performed in Bengall (Coult, 1731):

Here follows one account of the operation of inoculation of the smallpox as performed here in Bengal taken from the concurring accounts of several Bhamans and physicians of this part of India.

The operation of inoculation called by the natives *tikah* has been known in the kingdom of Bengall as near as I can learn, about 150 years and according to the Bhamanian records was first performed by one Dununtary, a physician of Champanager, a small town by the side of Ganges about half way to Cossimbazar, whose memory is now held in great esteem as being thought the author of this operation, which secret, they say, he had immediately of God in a dream.

Their method of performing this operation is by taking a little of the pus (when the smallpox are come to maturity and are of a good kind) and dipping these in the point of a pretty large sharp needle. Therewith make several punctures in the hollows under the deltoid muscle or sometimes in the forehead, after which they cover the part with a little paste made of boiled rice.

When they want the operation of the inoculated matter to be quick they give the patient a small bolus made of a little of the pus, and boiled rice immediately after the operation which is repeated the two following days at noon.

The place where the puncture were made commonly festures and comes to a small suppuration, and if not the operation has no effect and the person is still liable to have the smallpox but on the contrary if the punctures do suppurate and no fever or eruption ensues, then they are no longer subject to the infection.

The punctures blacken and dry up with other pustules.

The fever ensues later or sooner, according to the age and strength of the person inoculated, but commonly the third or fourth days. They keep the patient under the coolest regimen they can think of before the fever comes on and frequently use cold bathing.

If the eruption is suppressed they also use frequent cold bathing. At the same time they give warm medicine inwardly, but if they prove of the confluent kind, they use no cold bathing, but keep the patient very cool and giving cooling medicine.

3.2. Method of inoculation for smallpox (Holwell, 1767)

Inoculation is performed in Indostan by a particular tribe of Bramins, who are delegated annually for this service from the different colleges of Bindobund, Eleabas, Banaras, etc. over all the distant provinces; dividing themselves into small parties, of three or four each, they plan their travelling circuits in such wise as to arrive at the places of their perspective destination some weeks before the usual return of disease; they organise commonly in the Bengall provinces early in February, although they some years they do not begin to inoculate before March, deferring it until they consider the state of the season, and acquire information of the state of the distemper.

The inhabitants of Bengall, knowing the usual time when the Bramins annually return, observe strictly the regimen enjoined, whether they determine to be inoculated or not; this preparation consists only in abstaining for a month from fish, milk, and ghee (a kind of butter made generally of buffalo’s milk); the prohibition of fish respects only the native Portuguese and Mahomedans, who abound in every province of the empire.

When the Bramins begin to inoculate, they pass from house to house and operate at the door, refusing to inoculate any who have not, on a strict security, duly observed the preparatory course enjoined them. It is no uncommon thing for them to ask the parents how many pocks they choose their children should have: Vanity, we should think, urged a question on a matter seemingly so uncertain in the issue; but true it is, that they hardly ever exceed, or are different, in the number required.

When the before recited treatment of the inoculated is strictly followed, it is next to a miracle to hear, that one in a million fails of receiving the infection, or of one that miscarries under it; of the multitudes I have seen inoculated in that country, the number of pustules have been seldom less than fifty, and hardly ever exceeded two hundred. Since, therefore, this practice of the East has been followed without variation, and with uniform success from the remote known times, it is but justice to conclude, it must have been originally founded on the basis of rational principles and experiment.

3.3 Dharampal’s comments on inoculation

Till 1720, when the wife of the then British Ambassador in Turkey, having got her children successfully inoculated, began to advocate its introduction into Britain, the practice of inoculation was unknown to the British medical and scientific world. Proving relatively successful, though for a considerable period vehemently opposed by large sections of the medical profession and the theologians of Oxford etc., awareness grew about its value and the various medical men engaged themselves in enquiries concerning it in different lands.

Inoculation against the smallpox seems to have been universal, if not throughout, in large parts of Northern and Southern India, till it was banned in Calcutta and other places under the Bengal Presidency (and perhaps elsewhere) from around 1802-3. Its banning undoubtedly was done in the name of ‘humanity’, and justified by the Superintendent General of Vaccine Inoculation in his first report in March 1804. (A vaccine, from the Latin *vacca*, meaning cow, for use in the inoculating against small pox was manufactured by Dr. E. Jenner in 1798. From then on this vaccine replaced the previous ‘variolous’ matter, taken from human agents. Hence the method using the ‘vaccine’ came to be called ‘Vaccine Inoculation’.)

After giving the details of the indigenous practice, Holwell stated "When the before recited treatment of the inoculated is strictly followed, it is next to a miracle to hear, that one in a million fails of receiving the infection, or of one that miscarried under it." It is possible that Holwell's information was not as accurate as of the newly appointed Superintendent General of Vaccine Inoculation in 1804. According to the latter fatalities amongst the inoculated were around one in two hundred amongst the Indian population and amongst the Europeans in Calcutta, etc. "one in sixty or seventy". The wider risk, however, seems to have been in the spreading of disease by contagion from the inoculated themselves to those who for one reason or another had not been inoculated.

So what, till the latter part of the eighteenth century, when practised universally in any tract, was a relatively successful method and involved no contagious effect, as all were then similarly inoculated, by 1800 had begun to seem a great hazard to the Europeans in Calcutta. But in spite of the banning, prohibitions, etc. resorted to in Calcutta and other cities and towns, the introduction of vaccine inoculation was very halting. Such halting development must have been caused by insufficient provisions of resources or by sheer indifference. Or as hinted by the officiating Superintendent General of Vaccination for N.W.P. (the present U.P.) in 1870, it may also have been caused by the peoples' reluctance to get vaccinated as, according to this authority, this indigenous inoculation possessed more "protective power than is possessed by vaccination performed in a damp climate". Whatever the causes, the indigenous inoculation seems to have been still practised around 1870. For areas near Calcutta those who were not so inoculated are estimated at 10% of the population about 1870 and for the Benares area at 36%. The frequent smallpox epidemics which were rampant in various parts of India in the nineteenth and early twentieth century may largely be traced back on the one hand to the state's backwardness and indifference in making the requisite arrangement for universal vaccination, and on the other hand to having difficult by not only withdrawing all support to it but also forcing it to be practised secretly and stealthily.

3. Surgery *(Scott, Extracts of letters to J. Banks, 1790-1801)*

You will think the paper on putting on noses on those who have lost them in an extraordinary one. I hope to send you by the later ships some of the Indian cement for uniting animal parts.

In medicine I shall not be able to praise their science very much. It is one of those arts which is too delicate in its nature to bear war and oppression and the revolutions of governments. The effects of surgical operation are more obvious, more easily acquired and lost by no means so readily. Here I should have much to praise. They practice with great success the operation of depressing the chrystalline lens when become opaque (formation of a cataract) and from the time immemorial they have cut for the stone at the same place which they now do in Europe. These are curious facts and I believe unknown before to us.

4. **Ice making** *(Barker, 1775)*

The process of making ice in the East Indies having become a subject of speculation, I beg permission to present you with the method by which it was performed at Allahabad, Mootegil, and Calcutta, in the East Indies, lying between 25.5 and 23.5 degrees on North latitude. At the latter place I never heard of any persons having discovered natural ice in the pools or cisterns, or in any waters collected in the roads; nor has the thermometer been remarked to descend to the freezing point; and at the former very few only have discovered ice, and that but seldom. But in the process of making ice at these places it was usual to collect a quantity every morning, before the sun-rise (except in some particular kinds of weather, which I shall specify in the sequel) for near three months in the year: viz. from December till February.

The ice-maker belonging to me at Allahabad (at which place I principally attended to this enquiry) made a sufficient quantity in the winter for the supply of the table during the summer season. The methods he pursued were as follows: on a large open plain, three or four excavation were made, each about thirty feet square and two deep; the bottoms of which were strewed about eight inches or a foot thick with sugar-cane or the stems of the large Indian corn dried. Upon this bed were placed in rows, near to each other, a number of small, shallow, earthen pans, for containing the water intended to be frozen. These are unglazed scarce a quarter of an inch thick, about an inch and a quarter in depth, and made of an earth so porous, that it was visible from the exterior part of the pans, the water had penetrated the whole substance. Towards the dusk of the evening, they were filled with soft water, which had been boiled, and then left in the afore-related situation. The ice-makers attended the pits usually before the sun was above the horizon, and collected in baskets what was frozen, by pouring the whole contents of the pans into them, and thereby retaining the ice, which was daily conveyed to the grand receptacle or place or preservation, prepared generally on some high dry situation, by sinking a pit of fourteen or fifteen feet deep, lined with straw, and then with a coarse kind of blanketing, where it is beat down with rammers, till at length its own accumulated cold again freezes and forms one solid mass. The mouth of the pit is well secured from the exterior air with straw and blankets, in the manner of the lining, and a thatched roof is thrown over the whole. It is here necessary to remark, that the quantity of ice depends materially on the weather; and consequently, it has sometimes happened that no congelation took place. At others, perhaps, half the quantity will be frozen; and I have often seen the whole contents formed into a perfect cake of ice: For I have frequently remarked, that after a very sharp cold night, to the feel of the human body, scarce any ice has been formed; when at other times the night has been calm and serene, and sensibly warmer, the contents of the pans will be frozen through. The strongest proof of the influence of the weather appears by the water in one pit being more congealed than the same preparation for freezing will be in other situations, a mile or more distant.

To reason physically upon this process of making ice, it may be said, that had the thermometer been suspended in the air, free from every other body capable of communicating heat, in some parts of the night during the cold months of December, January, and February, the quicksilver might have `descended to the freezing point the water, being artfully placed in a similar situation contained in thin porous pans, and supported by a substance little capable of communicating heat from the earth might also freeze, and continue in a state of congelation till the heat of the morning came on. I say this may be possible; but at the same time I must beg leave to observe, that during my residence in that quarter of the globe, I never saw any natural ice. I cannot declare that the thermometer has not descended to the freezing point during the night, because I never made the necessary observations; but the water in every other situation, excepting in the pans, has not appeared to be in a freezing state. The climate may probably contribute in some measure to facilitate the coagulation of water, when placed in a situation free from the heat of the earth, since those nights in which the greatest quantity of ice has been produced, were as I before observed, perfectly serene, the atmosphere sharp and thin, with very little dew after midnight. Many gentlemen, now in England, have made the same remarks, in their frequent visits with me to the ice-pits. The spongy nature of sugar-canes, or stems of the Indian corn, appears well calculated to give a passage under the pans to the cold air; which, acting on the exterior parts of the vessels, may carry off by evaporation a proportion of the heat. The porous substance of the vessels seems equally well qualified for the admission of the cold air internally; and their situation being full a foot beneath the plane of the ground, prevents the surface of the water from being ruffled by a by small current of air, and thereby preserves the congealed particles from disunion. Boiling the water is esteemed a necessary preparative to this method of congelation; but how far this may be consonant with philosophical reasoning, I will not presume to determine.

5. Iron and Steel

5.1 Manufacture of Iron in central India (Franklin, 1835)

Charcoal is universally used in India for smelting iron, as the natives have no knowledge of coal, nor could they use it with their present refineries, because they are totally inadequate to the reduction of highly carbonised metal.

Their smelting furnaces, though rude in appearance, are nevertheless very exact in their interior proportions, and it has often surprised me to see men who are unquestionably ignorant of their principle, construct them with precision, in so simple a manner.

The iron was made over to Captain Presgrave of the Sagar Mint (an officer Very capable of judging with regard of its quality). He wrought it up into bars and rods for an iron suspension bridge on which he was then employed and the following is his report.
“I tried all the descriptions of ore and made experiments on roasting it – result of which could only be ascertained by making the iron, the first six marks constituted the bulk of the quantity submitted for trial, and their iron results may be safely taken as a fair average; the other three are the result of my experiments on roasting of the ore – previous to smelting.

The first six marks, afford bar iron (as far as my knowledge allows me to judge) of most excellent quality, possessing all the desirable properties of malleability, ductility at different temperatures and tenacity for all of which I think cannot be surpassed by the best Swedish iron; the second description consisting of three last numbers in the accompanying statement has produced very good bars, but in forging and working it up, the iron appears somewhat harder, probably from it still containing a portion of carbon; the different marks varied in yielding from 50 – 60.25 % in bars, the average from the whole being rather more than 55.74 %".

5.2. Excerpt from letters sent by Scott (1790-1801)

I enclose in one of the boxes a specimen of a kind of steel which is called wootz and is in high esteem among Indians. It appears to admit of a harder temper than anything we are acquainted with. I should be happy to have your opinion of its quality and composition. It is employed here for covering that part of gun-locks which the flint strikes, for cutting iron on a lathe, for chisels for cutting stones, for files and saws and for every purpose where excessive hardness is necessary. You must carefully observe that it cannot bear anything, beyond a very slight heat, which makes its working very tedious to the blacksmiths. It has a still greater inconvenience. It cannot be welded with iron or steel. It is only joined to them by screws and other contrivances. The blacksmiths, who work in wootz, generally consider it is a separate art and so do not work in iron. When the heat is a little raised above a slight red heat, part of the mass seems to run and the whole is lost as if the substance consisted to metals of different degrees of fusibility.

5.3. Dharampal's comments on Indian steel

The substance which seems to have evoked most scientific and technical interest in the Britain of the 1790s was the sample of *wootz* steel sent by Dr. Scott to Sir J. Banks, the President of the British Royal Society. The same went through examination and analysis by several experts (Mushet, Pearson, 1795). It was found in general to match the best steel then available in Britain, and according to one user, "promises to be of importance to the manufactures of Britain (Heyne, 1814). He found it "excellently adapted for the purpose of fine cutlery, and particularly for all edge instruments used for surgical purposes". After its being sent as a sample in 1794 and its examination and analysis in late 1794 and early 1795, it began to be much in demand; and some 18 years later the afore quoted user of steel stated, “I have at this time a liberal supply of Wootz, and I intend to use it for many purposes. If a better steel is offered to me, I will gladly attend to it; but the steel of India is decidedly the best I Have yet met with” (Heyne, 1814).

Whatever may have been the understanding in the other European countries regarding details of the processes employed in the manufacture of Indian steel, the British, at the time *wootz* was examined and analysed by them, concluded “that it is made directly from the ore; and consequently that it has never been in the state of wrought iron” (Pearson, 1795). Its qualities were thus ascribed to the quality of the ore from which it came and these equalities were considered to have little to do with the techniques and processes employed by the Indian manufacturers. In fact it was felt that the various cakes of *wootz* were of uneven texture and the cause of such imperfection and defects was thoughts to lie in the crudeness of the techniques employed.

It was only some three decades later that this view was revised. An earlier version in fact, even when confronted with contrary evidence as was made available by other observers in the Indian techniques and processes, was an intellectual impossibility. ”That iron could be converted into cast steel by fusing it in a closed vessel in contact with carbon” was yet to be discovered, and it was only in 1825 that a British manufacturer “took out a patent for converting iron into steel by exposing it to the action of carburreted hydrogen gas in a closed vessel, at a very high temperature, by which means the process of conversion is completed in a few hours, while by the old method, it was the work of from 14 to 20 days” (Heath, cited in Mushet).

According to J. M. Heath, founder of the Indian Iron and Steel Company, and later prominently associated with the development of steel making in Sheffield, the Indian process appear to combine both of the above early 19th century British discoveries. He observed: “Now it appears to me that the Indian process combines the principles of both the above desired methods. On elevating the temperature of the crucible containing pure iron, and dry wood, and green leafs, an abundant evolution of carburreted hydrogen gas would take place from the vegetable matter, and as its escape would be prevented by the luting at the mouth of the crucible, it would be retained in contact with the iron, which, at a high temperature, appears (from the above-mentioned patent process) to have a much greater affinity for gaseous then for concrete carbon; this would greatly shorten the operation and probably yet a much lower temperature then were the iron in contact with charcoal powder." (Cited in Mushet)

And he added: "In no other way can I account for the fact that iron is converted into cast steel by the natives of India, in 2 hours and a half, with an application of heat, that, in this country, would be considered quite inadequate to produce such an effect; while at Sheffield it requires at least four 4 hours to melt blistered steel in wind-furnaces of the best construction, although the crucibles in which the steel is melted are at a white heat when the material is put into them, and in the Indian process, the crucibles are put into the furnace quite cold".

The above quoted British authority however did not imply that the Indian practice was based on a knowledge "of the theory of his operations" by the Indian manufacturer. He felt it to be impossible "that the process was discovered by any scientific induction, for the theory of it can only be explained by the lights of modern chemistry".

6. **Indian Agriculture** (Walker, ca. 1820):

Nothing should surprise us more in the present condition of the Indian cultivator than his preserving industry, and well cultivated fields. Any other than a people of a buoyant spirit would have sunk under these circumstances.

The Hindoos have been long in possession of one of the most beautiful and useful inventions in agriculture. This is the Drill Plough. This instrument has been in use from the remotest times in India. I never, however, observed it in Malabar, as it is not required in rice cultivation in which its advantages have been superseded by transplanting. The system of transplanting is only in fact another method of obtaining the same object as by drill husbandry. It would be but just to adduce this, as another proof of ingenuity of this people and of their successful attention to this branch of labour.

[Dharampal notes that the drill plough is said to have been first used in Europe by one Joseph Locatelli of Carinthia (Austria) in 1662. Its introduction in England dates from 1730.]

They have a variety of implements per husbandry process, some of which have only been introduced into England in the course of our recent improvements. They clean their fields both by hoeing and hand weeding; they have weeding ploughs, which root out and extirpate the weeds. A roller would be useless on rice grounds, which are always wet and frequently an equal mixture of water and mud. The place of the roller is supplied by an instrument which levels or smooths the grounds, without turning on an axis. They have also mallets for breaking clods, the usual assortment of hoes, harrows and rakes.

It is the practice in many parts of India to sow different species of seeds in the same field. This practice has been censured, but it is probably done for the same reason that our farmers sow rye-grass and clover with wheat, barley, or oats; tares with rye; beans with peas; vetches and corn, etc.

It has been found by experience that these crops not only thrive in the same field; but improve each other. Rye and oats for instance, serve to support the weak creeping tares, and add besides to the bulk of the crop by growing through the interstices. Clover and rye grass are sheltered by the corn. This analogy will apply to the husbandry of India. These similar experiments may be carried further, where the climate and soil are superior. In India different kinds of seeds when sown in the same field are kept separate by the Drill, or they are mixed together, and sown broadcast. In the last case they are commonly cut down as forage. A plant called sota gowar, is sown broadcast with sugar cane in Guzerat (Gujarat). The gowar serves as a shelter to the sugar cane, from the violent heat of the sun, during the most scorching season of the year. Joar and badgery are sown together, in the same country late, not for the sake of a crop, but for straw, which is very nutritive, and very abundant. This is one of the instances in which the natives provide a green crop for their cattle. Other grains are sown both together and separately, merely for their straw. Soondea, darrya joar, rateeja and goograjoar are sown together: but with the exception, of goograjoar which is allowed to ripen, the rest are reapt while they are green.

It is evident that these examples are not founded on bad principles, and that they are in conformity with the best practice of farming. They evince the care of the Hindoo husbandman to provide food for his labouring cattle. This is an object to which I have generally seen him attentive; but in many parts of India during the dry season it is extremely difficult, and often exceeds the impoverished means of the cultivator, to lay in a sufficient supply. He is sensible enough of the want, and does his utmost to scrape together, all the heterogeneous substances that are within his reach. In some parts of India, hay is not made, in other parts it is a regular crop, stacked and preserved. This is the case in Guzerat, and some other pergunnahs. The hay is cut down not by the scythe but by the reapers hook: It is dried and brought home in carts. The stacks are generally of an oblong shape something like our own, but often of much larger dimensions than any that I have seen in England. The stack is not thatched merely, but covered by a movable roof. In those parts of India where hay is not made and which are I believe unfavourable to this kind of crop, the cattle are fed with the roots of grass, very like our fiorin, with straw, and especially with the straw of joaree, all the which are considered to be very nourishing food. The roots of this grass are preferred by our own people in the Carnatic to hay. Besides the Hindoo in many parts of India, prepares crops of pulse, solely for the use of his domestic animals. In some place he feeds them with carrots.

The practice of watering and irrigation is not peculiar to the husbandry of India, but it has probably been carried there to a great extent, and more laborious ingenuity displayed in it than in any other country. The vast and numerous tanks, reservoirs, and artificial lakes as well as dams of solid masonry in rivers which they constructed for the purpose of fertilizing their fields, show the extreme solicitude which they had to secure this object.

[Dharampal notes that the above observation is in dramatic contrast to the present day book accounts of the comparative absence of artificial irrigation in eighteenth century India (Majumdar et al., 1967).]

Besides the great reservoirs for water, the country is covered with numerous wells which are employed for watering the fields. The water is raised by wheel either by men or by bullocks, and it is afterwards conveyed by little canals which diverged on all sides, so as to convey sufficient quantity of moisture to the roots of the most distant plants. When these are seen in operation it gives the most cheerful picture of quiet and useful industry, that can occur even to the imagination. The very sight of it conveys to the mind peace and tranquillity.

4. Discussion

After reading the above excerpts, it is natural to wonder how our ancestors could achieve all this without access to libraries, computers, and other sophisticated equipment. It is also natural to reflect on the present situation in India, which is quite different. Most of the research work in the leading Indian institutions is motivated by ideas and problems generated in Western countries. In most fields, we have become followers rather than leaders. Why have the springs of creativity dried up? Is it because the present educational system stifles the spirit of enquiry? Is it because a large proportion of the people engaged in teaching and research do not really enjoy their vocation? Is it because the hustle and bustle of modern living, with its attendant insecurities, deadlines, and distractions provide little time for contemplation? Is it because centuries of indigenous knowledge about various procedures and processes were abandoned, over a relatively short period, in favour of the current scientific approach? Is it because our ancestors observed nature more keenly than we do nowadays? As a hymn from the Rig Veda puts it: “Who knows for certain? Who shall here declare it?”

Fig. 1 The Observatory at Benares (reproduced from Barker, 1777, with permission from the Royal Society of London).

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