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# WHY DID THE SCIENTIFIC REVOLUTION TAKE PLACE IN EUROPE AND NOT ELSEWHERE ?*

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## INTRODUCTION

Modern science emerged in Europe during the period 1450-1700 A.D. This emergence, termed 'Scientific Revolution' by science-historian A. Koyre in 1943, has been of far reaching importance in human history.[1,2] From that period begins the period of ascendancy of the West over the rest of the world.[3] The high Asian civilisations of India, China and the Islamic Middle East have been put on the defensive and must somehow adjust to changes induced in the world by the Scientific revolution.

In view of the importance of modern science and technology it is imperative to enquire as to "What caused the scientific revolution in Europe during the period 1450-1700 A.D. ?" A lot of thought and research has been devoted in the West to elucidate this query by the historians of science, technology and intellectual development.[2] There are no agreed final answers but it is still worthwhile to look at various possible answers which have been put forward. Such an exercise is even more worthwhile for us in nonwestern nations where modern science and technology has still not developed deep roots in view of its rather recent introduction there. We are naturally interested in finding out as to "Why did the scientific revolution not take place in one of the other high civilisations such as those of India, China or the Middle East ?" Could it be that some of the factors inhibiting the growth of modern science and technology are still operative in these areas ? A lot of research, in addition to what is already available, is needed to solve these important problems.[4-6]

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## ANCIENT VERSUS MODERN SCIENCE AND TECHNOLOGY

Before proceeding further with a review of the various theories about the origins of modern science and technology, it is worthwhile to contrast it with ancient science and technology.

There has clearly always been a certain amount of technological knowledge in every human society. It was necessary for survival, and if by 'science' we refer to any system of thought which tries to make sense of nature, then there has been a certain amount of science as well.

Most of these ancient sciences, before modern science, were rather qualitative and imprecise. The reasons are as follows. One had still not thought of the procedure of forming precise mathematical hypotheses about nature and then deriving their exact quantitative consequences which could then be tested. In fact the importance of testing theories by subjecting nature to well formed questions through controlled arrangements, *i.e.* the experimental method, had also not been discovered yet. In the absence of these procedures of formulating and validation it is very hard to make systematic progress and to discard any particular theory. As such all kinds of plausible looking scientific ideas can coexist. This is generally the situation with ancient science. As Whitehead once said, 'the essential discovery of modern science was the scientific method itself'. It is the appreciation and practice of the scientific method which has led to the progress of science being cumulative and exponentially increasing instead of being erratic.

The only exception to the charge of impreciseness of ancient science was ancient astronomy. Astronomy was however regarded not as a branch of science but of mathematics. This tradition survived until quite recently. Recall that astronomy was included in mathematics department, and not in the department of physics, in British Universities in the early part of the present century. Even in astronomy, which was essentially positional astronomy, one was satisfied with a phenomenological fit of the data on planetary position in ancient astronomy and was not concerned with any deeper understanding.

Ancient technology was also empirical, ad hoc and with rather small amount of a theoretical underpinning. Again it was not possible to systematically improve the existing technologies. The contrast between traditional and modern technology is brought out in a rather vivid manner in the famous war novel *The Bridge on the River Kwai* by Pierre Boulle. There he contrasts the methods of building a bridge in the traditional Japanese manner and according to the modern scientific method by English prisoners of war.[7]

Thus while all ancient high civilisations of Greece, Rome, India, China, Middle East and others had a certain amount of science and technology, they all suffered from a lack of discovery of the "scientific method" and did not develop into modern science and technology. Before coming to the more recent theories about "why the scientific revolution took place in Europe and not

elsewhere ?" We will first have a look at some of the earlier thinking about this question.

## ROLE OF GENIUS

William Whewell, master of Trinity College, published his three volume *History of Inductive Sciences* in 1837. It is one of the earliest histories of science and, as such, he had to take some stand on the causes of the scientific revolution. He underlined the role played by unusual persons of genius.

Incidentally the name of Whewell, though primarily known now to historians and philosophers of science, has a claim to be better known by the scientific community at large. After all it was he who coined the words 'scientist' and 'physicist'. When Faraday wrote to him asking his advice about what to call the two electrodes it was he who, ignoring various suggestions by Faraday, wrote back that they should be called 'cathode' and 'anode' and that is what they are called. He also coined the words 'eocene', 'miocene' and 'pliocene' among others.[8]

According to Whewell men of genius arise now and then who can ask the right sort of questions, think in right and productive directions and suggest the right answers. The occurrence of such men is, naturally, a rare thing. Science progresses when these men arise and languishes or stagnates when they are not there. In fact it is hard not to be impressed by people like Copernicus (1473-1543), Kepler (1571-1630), Galileo (1564-1642) and Newton (1642-1727) who ushered in the scientific revolution. They are all physicists and astronomers as these sciences spearheaded the breakthrough. Incidentally A. Koestler in his account *The sleepwalkers* takes the view that the contribution of geniuses is achieved not through a conscious process but rather through a process akin to sleepwalking. They unwittingly stumble on to great discoveries.

This view of Whewell is quite popular and caters to our sense of hero worship. It is believed by probably most scientists at least implicitly. It is subscribed to by many historians of sicence as well. A. Koyre has emphasized the role of Galileo.[9] G. de Santillana has brought out the role of F. Brunneleschi (1377-1446).[10] Whitehead called the seventeenth century as a "century of Genius." Butterfield's *The Origins of Modern Science* is also pervaded by this viewpoint.

The real question about the role of Geniuses is not about the quality and significance of their contribution. They, of course, contributed significantly. But is that the cause, or a prime cause, for the origin of the scientific revolution ? There have been persons of unusual brilliance in all periods and at all places. Persons like Plato (427-347 B.C.), St. Thomas Aquinas (1225-1274), Diṇnāga (fl. 425) or Śankarācārya (788-820) were such men in the intellectual field. But they were not attracted to science. Does it not depend on what a particular society considers worthwhile ? Why were so many geniuses attracted to science at that particular period in European history ?

## SCIENCE VS THEOLOGY

As is well known Galileo was forced to recant his scientific opinions before the inquisition. He confessed

> "I, Galileo, being in my seventieth year, being a prisoner and on my knees, and before your eminences, having before my eyes the Holy Gospel, which I touch with my hands, abjure, curse and detest the error and the heresy of the movement of the earth."[11]

Before Galileo there was Giordano Bruno (1547-1600) who was burned at the stake for his opinions about space being infinite. Copernicus also is known to have waited some thirty years before publishing his *magnum opus, On the Revolutions of the Heavenly Bodies.* In fact Copernicus received the book on his death bed only.

In view of these well known instances it may appear natural to agree with the thesis of Andrew Dickson White. He was the first President and the first Professor of History at Cornell Univeristy. He published his views in his book *A History of the Warfare of Science with Theology* in 1896. The book was published in the milieu in which Darwin's theory of evolution, and especially his views concerning *The Descent of Man* (1871) were subjects of intense debates. The appeal of the book is evident from the fact that it has been reprinted repeatedly, *e.g.*, in a Dover Edition in 1955.[11] White believed that, but for suppression by organised religion, modern science would have inevitably developed much earlier.

Is then theology the culprit ? Some support to this may be available in the Indian context as well. Al-bīrūnī had already commented on it in his book on India (*c.*1030 A.D.).[12] He first noted that "It is perfectly known to Hindu Astronomers that the moon is eclipsed by the shadow of the earth and the sun is eclipsed by the moon. Hereon they have based their computations in the astronomical handbooks and other works." He is therefore very surprised as to how Brahmagupta "notwithstanding the abundance of his knowledge and the sharpness of his intellect" could write "some people think that the eclipse is not caused by the Head. This, however, is a foolish idea, for it is *he* in fact who eclipses.... For if the Head does not cause the eclipse, all the usages of the Brāhmaṇs which they practice at the moment of an eclipse viz their rubbing themselves with warm oil, and other works of prescribed worship, would be illusory and not be rewarded by heavenly bliss. If a man declares these things to be illusory, he stands outside of the generally acknowledged dogma, and that is not allowed".

Al-bīrūnī's conclusion was "I, for my part, am inclined to the belief that which made Brahmagupta speak the above mentioned words (which involve a sin against conscience) was something of a calamitous fate, like that of Socrates, which had befallen him..."

Even in the Islamic world these high standards of integrity of scientific thought under theological attack were found difficult to maintain later. The

theologian al-Ghazzālī's (1058-1111) attack on Islamic scientific tradition had enormous influence. Ibn-Rushd (1126-1198), known in Latin as Averroes, tried to answer it in his book *The Incoherence of the Incoherence* but this could not be heard. Santillanna says "all-Ghazzālī's famous eloquence, undistinguished intellectually as it is, and to us ethically uninspiring, went to building up the whirlwind of intolerance and blind fanaticism which tore down not only science, but the very school system, and the glorious ijtihād, the interpretation of the Qur'-ān."[13]

It looks clear that theology and other similar closed systems of thought and vested interests can and do hamper the progress of science which is an open system of thought. But still the influence of these pressures cannot be the whole story in the late rise of modern science.

It has been argued that the clash between Galileo and the church was not inevitable and a trial in somewhat different circumstances might have found Galileo alright.[14] Merton, Mason and Hooykass have even argued that the protestant reformation may even have triggered the scientific revolution.[15] As Thomas Sprat, an early Fellow of the newly formed Royal Society, noted "They both may lay an equal claim to the word Reformation ; the one having encompassed it in Religion, the other (i.e. Royal Society) purposing it in (Natural-) philosophy."[16] These are all debatable.

However, consideration of the Chinese case makes one pause for further thinking. Chinese Society has been rather free of theological dogma in its long history. Confucianism, which was the dominant creed, was ethical rather than theological. Taoism also invites one to live in harmony with nature.

## INTERNAL AND EXTERNAL FACTORS

So could it be that we have to look elsewhere for the solution of the problem ? We now come to more recent theories of the scientific revolution.

Let us raise the problem as to what attracts brilliant minds to any particular activity such as science. Without giving a complete answer one can at least list some factors.

There may be stages in which a particular scientific activity is intellectually stimulating and there are a lot of interesting problems on the verge of getting solved. This would be an attraction to join the activity. These reasons have to do with the internal dynamics of the growth of science and may be termed internal factors.

Another factor may be the view the society at large takes of a particular activity. If society values it highly, for whatever reasons, it may encourage brilliant people to participate in it. The reasons of the society may have to do with the self-image of the society, the utility of the activity to it or may refer to something more intangible. These reasons may be rooted in the technological,

economic, intellectual and social life of the society. One could refer to these as external factors.

We shall now try to isolate some of these factors. To isolate the possible internal factors let us look at medieval science in Europe.

## MEDIEVAL EUROPEAN SCIENCE

Most text book writers on science give the impression that there is no such thing as Medieval European Science. Further, whatever little science medieval Europe had was what they had inherited from Greece *via* the Arabs. Mach, in 1869, wrote in his famous and influential book *Science of Mechanics:* "dynamics was founded by Galileo . . . , no part of the knowledge and ideas on this subject with which we are now so familiar existed in Galileo's time, but . . . Galileo had to create these ideas and means for us."[17]

Since Mach's time a lot of work has been done on medieval intellectual history and, without detracting from Galileo's achievements and greatness, one has to now admit that there was a flourishing tradition of work in mechanics in medieval times. The credit for bringing this change of view, and starting the field of research in the field of medieval mechanics, goes essentially to the French catholic physicist Pierre Duhem.

Duhem, on the basis of his studies of medieval manuscripts, discovered the work of the scholastic teachers of natural philosophy, at the universities of Oxford and Paris—John Buridan, Albert of Saxony, Thomas Bradwardine, Nicole Oresme, and others—in the fourteenth century. He published his work during the first two decades of this century.[18] He claimed that Galileo was not an originator of modern dynamics but was only a vigorous defender of this earlier school of medieval dynamics against the authority of Aristotle and Averros restored by the Italian renaissance. He would have liked to thus put the origin of scientific revolution back into the fourteenth century and give the credit of the scientific revolution to the schoolmen.

Further work on the history of the medieval science by Maier, Moody, Claggett, Crombie and others has of course led to a reappraisal of Duhem's thesis.[19] Galileo did contribute key novel ideas to dynamics. The 'impetus' theory of John Buridan, at best, can be regarded as a precursor of his work. All the same he had a tradition of work in mechanics behind him. There is thus a certain amount of evolution also in the scientific revolution. Considering the fact that the Chinese did not develop such a tradition in mechanics, the importance of the schoolmen in channelling the discussion onto mechanics, and especially to problem of uniformly accelerated motion, cannot be denied. Galileo might not have worked in dynamics without it. It is amusing that it was these discussions on mechanics by the schoolmen which were denounced as arid by humanists, like Erasmus, of the European Renaissance.

In the Indian context there was some amount of discussion on the principles

of mechanics in the schools of *Nyāya* and *Vaiśeṣika* philosophy. These however never focussed on precise problems, like that of uniformly accelerated motion, and did not use mathematics in their discussion as was attempted by schoolmen at Oxford and Paris. As such they remained unproductive.[20]

## INTEGRATION OF MATHEMATICS WITH SCIENCE

One may note that in Europe the importance attached to a study of Aristotelian logic in the fourteenth century had shifted to the study of mathematics by the seventeenth century. How did this change come about ? Was it a natural development out of the work of medieval schoolmen ? That this was so is maintained by Clagget and others.

E.A. Burtt, in his remarkable book, *The Metaphysical Foundations of Modern Physical Science* (1924), argued however that the renewed emphasis on mathematics was due to a revival of Platonism during the Renaissance. A. Koyre also is of the same view. To quote Burtt

> "the greatest point of conflict between the dominant Aristotelianism and this somewhat submerged but still pervasive Platonism. The latter regarded universal mathematics of nature as legitimate, . . .; the universe is fundamentally geometrical ; its ultimate constituents are nothing but limited portions of space ; as a whole it presents a simple, beautiful, geometrical harmony. On the other hand the orthodox Aristotelian school minimized the importance of mathematics. Quantity was only one of the ten predicaments and not the most important. Mathematics was assigned an intermediate dignity between metaphysics and physics. Nature was fundamentally qualitative as well as quantitative ; the key to the highest knowlege must, therefore, be logic rather than mathematics. With the mathematical sciences allotted this subordinate place in his philosophy, it could not but appear rediculous to an Aristotelian for any one to suggest that his whole view of nature be set aside in the interest of a simpler but more harmonious geometrical astronomy. Whereas for a Platonist ( . . . ) it would appear a most natural, though still radical step, involving as it did the homogeneity of substance throughout the whole visible cosmos. However, Copernicus could take the step because, in addition to motive factors already discussed, he had definitely placed himself in this dissenting Platonic movement".[21]

E. Zilsel however attributes this development, *i.e.*, an emphasis on mathematics, in particular, and the scientific revolution itself in general to the advances in economy and the growth of rational, as opposed to empirical, technology.[22] Let us now look at these social, economic and technological factors.

## SOCIAL, ECONOMIC AND TECHNOLOGICAL FACTORS

Friedrich Engels, in a letter to Starkenburg written in Jan. 1894, emphasised

these factors : "If, as you say, technique largely depends on the state of science, science depends far more still on the *state* and the *requirements* of technique. If society has a technical need, that helps science forward more than ten universities. The whole of hydrostatics (Torricelli, *etc.*) was called forth by the necessity for regulating the mountain streams of Italy in the sixteenth and seventeenth centuries. ... But unfortunately it has become the custom in Germany to write the history of sciences as if it had fallen from the skies."[23]

Zilsel was among the earliest to take this Marxist point of view seriously. He connected the scientific revolution with the rise of capitalism in Europe. He pointed out a number of characteristics of this early capitalism which were conducive to the rise of the scientific spirit. These are as follows :

(i) In the feudal middle age the knights in their castles and clerics in their monasteries in the countryside were the dominant elements of the society. With capitalism the focus shifted to towns and to merchants and craftsmen. Science, not being a military or other worldly pursuit, was more likely to develop in the new setting.

(ii) The rapid growth of machinery at this period encouraged rational, as opposed to magical, thinking and provided real-life problems to be solved by science.

(iii) The hold of groups, such as guilds of craftsmen, and traditions weakened on people. People had to act as individuals, in competition with others, and not just as members of some umbrella-group. The rise of individualism was good for rational inquiry.

(Parenthetically we may note that the lack of individualism and the hold of caste and other groups may have done their damage in India.)

(iv) The base of capitalism is calculation and measurement as reflected in bookkeeping and the use of machines, not only for the production of goods but also for checking the quality and quantity of raw materials and output products. Luca Pacioli's *Summa de arithmetica* (Venice, 1494), the best textbook of its period, deals with double entry book-keeping as well. The famous Dutch scientist Simon Stevin, known for his early work on mechanics, also deals with it. Stevin dedicated his paper, containing the first description of decimal fractions, "To all astronomers, surveyors, measurers of tapestry, barrels and other things, to all mintmasters and merchants ...". The celebrated Copernicus, whom we mentioned in connection with relationship of Platonism with mathematics, wrote one of the earliest tracts on reform of the monetary system.

At the time of Renaissance, the university-educated scholars and humanistic literati, or the intellectual elite in general, were socially in the upper classes together with rich nobles, merchants and bankers. The intellectual elite used Latin somewhat like the Indian intellectual elite using Sanskrit in ancient times

or English at present. They strongly adhered to the Greek prejudice against manual labour which was born out of theirs being a slavery-based society. Thus university-trained physicians were intellectually content to write commentaries on Galen. The surgeons belonged with barbers and midwives, as was true in rural India even 50 years ago. Craftsmen, who worked with their hands, were beneath the notice of intellectuals. Even artists were considered no better than white washers. It is these craftsmen who were involved with the technological discoveries of the age such as the mariner's compass and guns, construction of paper and wire mills, blast furnaces and a host of other such things. They on the whole used the vernacular and did not have a formal education. The separation of Head and Hand, remarked on by B. Farrington—historian of Greek Science—was still very much there.[24]

As the pace of development quickened some of the superior craftsmen, *i.e.*, those who needed more scientific knowledge for their work in contrast to others, such as artist-engineers, surgeons, instrument makers, surveyors, navigators, gunners made contact with university intellectuals. They also wrote various manual or texts in the vernacular for the use of their friends in their professions. At a certain stage in the development in technology the social barrier was broached and intellectuals began taking interest in the work of these superior artisans. We may remark that Galileo (1564-1642) was the first university-trained writer to write in a vernacular (in this case, Italian) as opposed to Latin. Lynn White Jr., author of that classic book *Medieval Technology and Social Change* (1962), has also argued that the roots of Galileo's thought "lay not only in the alluvium of inherited speculative and mathematical science but also in contemporary engineering." Galileo, indeed, opens his book *Discourses* (1638) with a remarkable description of the Venice arsenal which is seen by him as something leading to scientific thinking. W. Gilbert's book *De Magnete* (1600) was the first book by an academic based on his own experimental work.

According to Zilsel "the real science was born" when these two groups, *i.e.*, academics and superior craftsmen, came together after about 1550 A.D. The theoretical and experimental methods could be unified thereby at last. Similar views have been expressed by J.G. Crowther, J.H. Randall and others.[25]

## SCIENCE AND SOCIETY IN ASIA

We have already referred to Al-bīrūnī's comments on Brahmagupta. Debiprasad Chattopadhyay, in his remarkable book *Science and Society in Ancient India* has analysed the state of medical science and the status of physicians.[26] The physicians of ancient India, as represented in *Caraka* and *Suśruta Saṃhitās* and other medical texts, had developed a remarkable modern scientific outlook. They were however regarded quite low in the social scale. The *Dharma Sūtras* of Āpastamba has the admonition "The food given by a physician, a surgeon, a hunter, a fowler, an unfaithful wife, or eunuch must not be eaten." In case there

is any doubt about the company in which a medical doctor is supposed to be Gautama Dharmasūtra adds criminals and such other persons to the list. Artisans are also included in the same list. Food however may be accepted from "a trader who is not an artisan." According to Manu "the food received from a doctor is as vile as pus." Bhīṣma in *Mahābhārata* also agrees with Manu as he asserts that "a gift offered to the physician becomes as vile as pus and blood." According to Manu the practice of medicine must be restricted to base born *Ambaṣṭhas.* Of course one must emphasise here that these *dharma sūtras* represent the views and prejudices of priestly classes and these were probably shared widely. Luckily they were probably not the secular laws of the land. All the same the debilitating effects of such social reception of science of medicine were clearly conducive to a scientific revolution. Being also a slave-owing society there was probably not much motivation for an improvement of technology. The head and hand remained, generally speaking, in isolation, even opposition, to each other in ancient India just as in ancient Greece.

The case of Chinese society is somewhat different and a little more problematical. They had bureaucratic feudalism and the society was ruled by civil servants (mandarins), who were chosen on the basis of competitive civil service examination based on the classics. Slave labour was not an important ingredient and there was a money economy. Of course merchants did not have much prestige. The mandarins and skilled artisans had a chance to interact and there was state support for large projects such as hydraulic ones. Of course as a result it can be fairly asserted that technology in the period of a thousand years before 1500 A.D. was probably the most advanced in the world. Still neither the scientific revolution, nor the transition to capitalism, did come about.[27]

Could it be that this was due to lack of a conception of "a divine law over non-human nature" which was there in Europe and which began to be taken seriously at the time of renaissance ?

According to Needham, Chinese did not develop such a conception from their conception of human law. They had a bad experience of legal precision during the period of dominance of "school of Legalists." Besides, the universe was conceived as a harmony in which different parts behaved according to their intrinsic nature and not because of some law imposed from outside. Chinese also did not develop the concept of a 'godhead' who acts as a divine law giver. In sixteenth century Europe a cock could be prosecuted for laying an egg and sentenced to being burnt alive as it was considered 'a heinous and unnatural crime.' There is an early recorded example of such a prosecution from Basel in 1474 and a late one in 1730 from Switzerland. Such a prosecution would have been considered ludicrous in China but, all the same, one wonders with Needham, "Whether the state of mind in which an egg-laying cock could be prosecuted at law was necessary in a culture which should later on have the property of producing a Kepler."[28]

## CONCLUDING REMARKS

We have tried to give above a flavour of various theories on the origins of scientific revolution. None of them is totally satisfactory by itself. All of them probably reflect some aspect or the other of the truth.

There are also many other possibly relevant factors which have been considered. To take an example one could consider the role of printing, the Gutenberg revolution (1450 A.D.), in this context. It has been persuasively argued that the European consciousness underwent a drastic change from aural-oral mode to visual mode as a result of the impact of the printed word.[29] Could this have caused the scientific revolution as Walter Ong seems to suggest in his study of Ramus.[30] But if one argues along these lines one should also explain the Chinese case who, after all, were the original 'printed word' people.

The basic difficulty in understanding the origins of scientific revolution, as it must have become clear by now, is that it is an unique event. It happened only once. We could regard it as a miracle and leave it at that as miracles cannot be understood. This course we do not pursue, or believe, as it leaves us intellectually dissatisfied. The method, we have followed above, for the elucidation of the origins relies heavily on a comparative study of science, technology and society in various ancient civilisations.

As we have mentioned earlier we hope to learn of the causes of non-occurrence of scientific revolution outside Europe so that if similar factors are operative now we could remove them. Could it be, looking at the other side of the coin, that a study of the factors promoting or inhibiting an implant of scientific culture in non-western countries at present might teach us something about the origins of scientific revolution itself ? A study of introduction of science in Japan during Meiji period would clearly be interesting in this connection.

We may, further, draw attention to cultural renaissance which took place towards the end of the last century in India. This period produced people like Bankim Chatterjee, Ishwar Chandra Vidyasagar, Ram Mohan Roy, Keshub Chandra Sen in humanities ; Ramkrishna, Vivekananda and Dayananda in religion. In science we have Ashutosh Mukherjee, J.C. Bose, P.C. Roy and the foundation of the Indian Association for the Cultivation of Science (1876) by Mahendralal Sircar. This movement later produced C.V. Raman, M.N. Saha, S.N. Bose and others. This presents itself as a small scale version of what happened in Europe during 1450-1700 A.D. when modern science arose there. A deeper study of the social, economic, technological and intellectual aspects of the history of this period of the Indian history might be an illuminating one.

## ACKNOWLEDGEMENT

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