REVIEW ARTICLE

CHINA, EUROPE AND THE ORIGINS OF MODERN SCIENCE

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Why China lost its former lead and fell behind Europe is almost the first question which a layman asks about Chinese civilization, a question from which sinologists tend to shrink into their separate compartments, afraid of being caught up in inconclusive generalizations. Recently it has appeared in the context of a relatively new discipline, the history of science, presented in a more exact form which gives it a new claim on our attention. We now know that the supposed stagnation of China and the rest of Asia was illusory, their changes being slow only in relation to the accelerating development of Europe since the Renaissance, a transformation for which the only precedent is the discovery of agriculture and the transition from nomadic to settled life during the Neolithic Age. The crucial event in this process was the "Scientific Revolution" in the seventeenth century, the refining of methods of stating hypotheses in mathematical terms and testing them by controlled experiment. This was the "discovery of how to discover", the take-off for an accelerating accumulation of knowledge, and its application to technology generated the Industrial Revolution. It seems then that we have only to ask, "Why was there a Scientific Revolution in Europe about 1600?", "Why was there no Scientific Revolution in China or India?", questions which look as though they are two sides of one coin.[1]

[1] A suspicion of generalizations about nature which depend solely on authority or *a priori* deduction or are presented in untestable "proto-scientific" forms, a recognition that the final appeal is to observation and experiment, are preconditions of modern science, but have appeared more than once in the histories of Greece, Christendom and China without leading to a Scientific Revolution. In China the later Mohists in their writings on the sciences (*c.* 300 B.C.) confine themselves to strictly testable explanations in optics, mechanics and economics, ignore such proto-sciences as medicine, and reject the proto-scientific theory of the ascendancies of the Five Elements (Mohist Canons, B 16–31, 43). In Mediaeval Christendom the experimental method was developed by Grosseteste (*c.* 1170–1253), only to drop from sight during the fourteenth century (A. C. Crombie, *Medieval and early Modern Science*, New York, 1959, Vol. 2, 1–35, 103–21). The Scientific Revolution required not only the recognition in principle of the importance of empirical testability, but the refining of the techniques of mathematization, observation and experiment in at least one crucial discipline. Historically the event followed the supersession of the qualitative physics of Aristotle by a quantitative and

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It is the second question which interests inquirers into Chinese science. I intend shortly to suggest that although the positive question is real and important there is something wrong with the negative question, but whether it is conceptually confused or not there is no doubt that important social and cultural differences between China and the West have been brought to light by those who insist on asking it. The search for an answer has provided much of the impetus for Dr. Joseph Needham's great *Science and Civilization in China*, and in eight papers now assembled in one volume[2] he returns to the theme again and again. In these papers, each of which displays in miniature his nearly superhuman capacity for organizing his vast store of material in the service of a lucidly argued case, the development of his thought on this problem can be followed over twenty years. *On Science and Social Change* (1944) already asks "why did modern science not arise in China?", and gives a fairly straightforward Marxist answer influenced by the early Wittfogel: the bourgeoisie provided the setting of free and equal debate within which science can develop, but the growth of the bourgeoisie which accompanied the decay of European feudalism was not possible inside Asiatic bureaucratism. In this essay he does not yet make great claims for Chinese technology, being aware of few additions to the traditional list of Chinese inventions (gunpowder, printing, paper, the compass). His later researches revealed more and more inventions first attested in China, which he delights in listing in article after article (the mechanical clock, the driving-belt, the crank, efficient equine harness, the wheelbarrow, segmental arch bridges . . .). The more recent papers recognize the technological superiority of China over most of history as a second problem; he is inclined to find the explanation in the absence of the mass chattel-slavery which is commonly thought to have discouraged technological progress in Greece and Rome. By the time of *Science and Society in East and West* (1964) he gives equal weight to the questions "Why modern science had not developed in Chinese civilization (or Indian) but only in Europe?" and "Why, between the first century B.C. and the fifteenth century A.D., Chinese civilization was much *more* efficient than occidental in

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therefore strictly testable physics initially inspired by the sixteenth-century revival of the Pythagorean faith in number as the secret of the cosmos (Cf. Alexandre Koyré, *Metaphysics and Measurement*, Harvard University Press, 1968).

[2] *The Grand Titration: Science and Society in East and West* (London: Allen and Unwin, 1969), 350 pp. 63s.

Abbreviations: GT, *The Grand Titration;* SCC, *Science and Civilization in China*, Cambridge, 1954—Needham has also discussed the problem of the origin of scientific method in SCC 3/150–168.

I do not hesitate to apply the adjective "great" to Needham's work although like other sinologists I am aware that his linguistic understanding is below the highest available standards. The best qualifications in both sinology and science are unlikely to meet in one person whose native language is not Chinese, and it is lucky that there is someone who has come so near to combining them.

applying human natural knowledge to practical human needs?" Unsympathetic to the "internalist" approach to the history of science dominant for the last thirty years, he repeats his sociological explanation but in a much more developed and refined form, for which he acknowledges a debt to Jean Chesneaux and André Haudricourt. Although primarily interested in social and economic factors he considers with sympathy the possibility that the genesis of modern science required the concepts of linear time and of a divine legislator, in *Time and Eastern Man* and *Human Law and the Laws of Nature*.

The researches embodied in *Science and Civilization in China* have dispelled much of the haze which surrounded this issue. It is now clear that for most of its history the West showed no special bent towards technology. The three inventions which according to Francis Bacon had changed the face of the world, "those three which were unknown to the ancients, and of which the origin though recent is obscure and inglorious, namely, printing, gunpowder and the magnet" (that is, the magnetic compass), all reached Europe from China. Nor is it true that the West already had science while China only had technology. The systems based on the Yin and Yang and the Five Elements which underlie Chinese alchemy, medicine, geomancy, do not seem to be different in kind from Mediaeval science, and if we prefer to speak of "proto-science" we must apply the name to both. The greater rationality of modern science is already present in Greek logic, geometry and philosophy, but for 2,000 years gave no technological advantage for those who had it over those who had not. It is still no doubt common to lump together Greek logic and the modern science to which it contributed under some such heading as "the generalized conception of scientific explanation and of mathematical proof" or the "rational conception of the cosmos as an orderly whole working by laws discoverable in thought".[3] This kind of description, which rouses Needham to polemic, illustrates, I would suggest, the mistake of looking for distinguishing features of a "Western civilization" conceived as a unity nearly three thousand years old which includes Greece and excludes Israel, instead of tracing the connexions of a "Western tradition" which is a stage, starting as far back as one chooses to make the cut, in one of the diverging and converging lines of development which go back to Egypt and Babylon (in which, for example, Christendom and Islam diverge out of the late Roman civilization on which Greece and Israel have converged). Indeed if we wish to find the best historical perspective for looking forward towards the Scientific Revolution, there is much to be said for choosing a viewpoint not in Greece but in the Islamic culture which from A.D. 750 reached from Spain to Turkestan. This was the first civilization in history which was in varying degrees the heir of all the great civilizations

[3] GT 42, 43.

of the Old World. It was in most cases the channel by which Chinese inventions reached the West, but it was also the meeting place of Indian numerals, zero and algebra and Greek geometry, and of the Hellenistic and Chinese influences which ran together in the alchemy which is one of the ancestors of chemistry. A pool in which older discoveries could mix and interact, Greek, Indian, Chinese (scarcely ever Roman), was an important preliminary of the "discovery of how to discover". From about A.D. 1000 Christendom set out on the enterprise of translating the corpus of Arabic learning into Latin (including the Arabic translations of Aristotle, Euclid, Galen, Ptolemy). When Arabic science passed into decline, of the three great cultures on its edges (China, India, Christendom) it was the last which inherited its great synthesis.

The vague old question "Why did China fall behind?" has therefore clarified and concentrated in recent decades; we might even dramatise it as "Why was Galileo born in Europe and not in China?":

> First of all it is essential to define the differences between ancient and medieval science on the one hand, and modern science on the other. I make an important distinction between the two. When we say that modern science developed only in Western Europe at the time of Galileo in the late Renaissance, we mean surely that there and then alone there developed the fundamental bases of the structure of the natural sciences as we have them today, namely the application of mathematical hypotheses to Nature, the full understanding and use of the experimental method, the distinction between primary and secondary qualities, the geometrization of space, and the acceptance of the mechanical model of reality. Hypotheses of primitive or medieval type distinguish themselves quite clearly from those of modern type. Their intrinsic and essential vagueness always made them incapable of proof or disproof, and they were prone to combine fanciful systems of gnostic correlation. In so far as numerical figures entered into them, numbers were manipulated in forms of "numerology" or number-mysticism constructed *a priori*, not employed as the stuff of quantitative measurements compared *a postiori*. We know the primitive and medieval Western scientific theories, the four Aristotelian elements, the four Galenical humours, the doctrines of pneumatic physiology and pathology, the sympathies and antipathies of Alexandrian proto-chemistry, the *tria prima* of the alchemists, and the natural philosophies of the Kabbala. We tend to know less well the corresponding theories of other civilizations, for instance the Chinese theory of the two fundamental forces Yin and Yang, or that of the five elements, or the elaborate system of symbolic correlations. In the West Leonardo da Vinci, with all his brilliant inventive genius, still inhabited this world; Galileo broke through its walls. This is why it has been said that

Chinese science and technology remained until late times essentially Vincian, and that the Galilean break-through occurred only in the West. That is the first of our starting points.[4]

Among earlier contributions to the problem Needham quotes the charming letter of Einstein to J. E. Switzer printed by Derek Price:

> Development of Western Science is based on two great achievements, the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, and the discovery of the possibility to find out causal relationship by systematic experiment (Renaissance). In my opinion one has not to be astonished that the Chinese sages have not made these steps. The astonishing thing is that these discoveries were made at all.[5]

Needham takes this as a slight on Chinese civilization and springs to its defence. But Einstein does not seem to be saying anything about Chinese limitations. He seems rather to be advising Switzer not to think that a discovery was always obvious because it is now familiar, to recover the fresh eye by which it is seen to depend on a nearly miraculous conjunction of improbable circumstances. For 1,400 years between Ptolemy and Copernicus the West remained satisfied with the geocentric theory although the heliocentric theory had already been proposed and the evidence tying the motions of at least the inner planets to the sun was still available, and it forgot Hero of Alexandria's steam engine for even longer; who are we to be surprised if other civilizations failed to notice things which in retrospect seem to have been just around the corner? One does not ask why an event did *not* happen unless there was reason to expect it, and nothing in the conditions even of Europe in the sixteenth century justifies thinking of the Scientific Revolution as an event due at a certain point of maturation, as though civilization were an organism with stages which it passes through unless its development is arrested. In the absence of grounds for expectation I explain why a house did catch fire (because someone left a cigarette burning), I do not go through all the other houses in turn explaining why they did not catch fire (no one was smoking, the wiring was sound, there were no bombs, no lightning . . .) The difference follows from the fact that like effects may have unlike causes; if the event does happen we can select from the possible causes, if it does not we may not be able to enumerate all the unrealized possibilities.

If the Western development after 1600 began from a single though complex discovery, that of the procedures which accelerate discovery, we are concerned with an event like the invention of the wheel or of metallurgy,

[4] GT 14, 15.

[5] Derek J. de Solla Price, *Science since Babylon* (New Haven 1961), 15, n. 10. The version quoted by Needham (GT 43) unobtrusively smooths Einstein's English.

which we are not surprised to find diffusing from a single centre where conditions for the invention are not visibly better than in many other places. We may of course find places lacking necessary conditions of an invention (the Polynesians did not invent skis because they have no snow), but for the most part it is conditions at the place of discovery which interest us. It would be pointless to ask why the Swiss did not invent skis for themselves before getting them from Norway in the nineteenth century, still more so to run over the list of maritime countries asking of each why its swimmers did not discover the crawl before its dissemination from the Pacific. But these considerations would not stop us asking the positive question, looking for conditions favourable to the inventions in Norway and Polynesia.

The positive and negative questions are inseparable only as long as we are thinking of the difference between China and the West as one of degree. "Why is China backward?" and "Why is the West ahead?" really are two ways of putting the same vague question. We tend to suppose that this is still so when we sharpen the issue to the occurrence or non-occurrence of the Scientific Revolution. But the questions remain two sides of the same coin only if we think of the event as having a single cause which is both necessary and sufficient, as in the more elementary kind of Marxist explanation ("Why did modern science emerge in Europe? – Because the bourgeoisie had broken free of the bonds of feudalism. What prevented it in China? – The shackling of the bourgeoisie by Asian bureaucratism.") But if Needham ever inclined to such a simplification certainly he does not now:

> Whatever the individual prepossessions of Western historians of science all are necessitated to admit that from the fifteenth century A.D. onwards a complex of changes occurred; the Renaissance cannot be thought of without the Reformation, the Reformation cannot be thought of without the rise of modern science, and none of them can be thought of without the rise of capitalism, capitalist society and the decline and the disappearance of feudalism. We seem to be in the presence of a kind of organic whole, a packet of change, the analysis of which has hardly yet begun. In the end it will probably be found that all the schools, whether the Weberians or the Marxists or the believers in intellectual factors alone, will have their contributions to make.[6]

Clearly the analysis of this complex of events would not explain or need to explain why the Scientific Revolution did not occur in China. It will hardly be suggested that the spontaneous emergence of modern science in China would have required the equivalents of any of these events except, arguably, the rise of capitalism.

When we ask the negative question, we assume that there are necessary

[6] GT 40.

conditions for a Scientific Revolution which were present in Europe but absent in China. This assumption might conceivably turn out to be correct; but if not, how are we to enumerate all the situations in which the event could have taken place, and prove that none existed in China, and why should we wish to do so? As Einstein perceived, we are not bound to ask why a civilization did *not* do something as improbable as exploring the possibilities of mathematizing its generalizations about nature and testing them by controlled experiment – a prospect less obvious one would think than that of a Swiss getting the idea of skis. Here it may be objected that the simple inventions we are using as analogies may be misleading us. There are scarcely any relevant preconditions for example of the invention of the boomerang, and scarcely any peoples on earth of whom one would wish to explain why they never got around to inventing it. But we would expect the birth of modern science to have a much more varied complex of preconditions, not the concomitant events considered in the last paragraph, but such heterogeneous factors as the meeting of Greek logic and geometry with Indian numerals and algebra, capitalism, the Christian sense of linear time and of a cosmic legislator. However, it is precisely when factors are interrelated that it is most difficult to show that any one of them is a necessary condition. If X is ill and Y is a nurse and they meet in a London hospital it does not follow that they could not have met earlier when they were in New York because X was well and Y was not yet a nurse. The combination of the mathematization of hypotheses and controlled experiment certainly requires some mathematics and some tradition of experiment, which is enough to explain why it did not happen among Australian aboriginals; but may it not be that where these and a few other conditions are satisfied the result could follow from any number of complicated, improbable, but quite different conjunctions of circumstances?

The trouble is that explanations of China's failure to attain modern science are generally no more than proofs that she was not following the route by which we arrived at it. We are shown that one of the interlocking factors in sixteenth-century Europe was missing in China, a kind of explanation which is liable to reduce itself to the vacuous observation that conditions in sixteenth-century Europe differed from those of any other place or time. The "why not?" question could be fruitfully asked only if it should prove possible to detach the factors from their historical situation and show that they are necessary as snow is necessary to the invention of skis, which we have no particular reason to expect. The problem can be seen in Needham's simplest version of his sociological argument, in the early essay *On Science and Social Change* (1944):

> As we have already seen above, the rise of the merchant class to power, with their slogan of democracy, was the indispensable accompaniment and *sine qua non* of the rise of modern science in the West. But in China the scholar-gentry and their bureaucratic feudal system always effectively prevented the rise to power or seizure of the State by the merchant class, as happened elsewhere.[7]

But the rise of the merchant class would be a *sine qua non* of the rise of modern science outside Europe only if there are necessary conditions which the merchant class alone can fulfil. Are such conditions implicit in the connexions which Marxists find between science and the rise of capitalism? We may instance the arguments that competing capitalists are attracted by the profitability of technical innovations, irrelevant to landowners whose income is rent; that science flourishes only in an atmosphere of free and equal debate, provided by the merchant class "with their slogan of democracy"; that the fusion of mathematics and experiment could happen only when the theoretical discoveries of Greek slaveowners were circulating among people not ashamed to work with their hands. Of course all these points are relevant to the positive question of how the Scientific Revolution came about. The close connexions between science and middle class attitudes and interests are plain enough; in English society at least science has hardly lived down its vulgar origins yet. But if we try to detach necessary conditions (a social force with a vested interest in technological advance, an atmosphere of free debate, people who could use both their minds and their hands, conditions which become vaguer the further one tries to detach them from the historical situation) it becomes less and less clear that they could be fulfilled only by the merchant class. In any case the conditions favourable to scientific advance in a merchant class have little to do with whether or not it has won political power. Galileo after all lived at a time when the medieval fight for republican institutions in the Italian cities had long ago been lost. Asian bureaucratism did not inhibit the growth of a flourishing bourgeois culture in late Imperial China: why should the political impotence of the merchant class be more of an obstacle to science than to the novel, which was already emerging in the sixteenth century? In Europe the Scientific Revolution did not wait for the seventeenth-century political struggle in England, but the novel did.

In the very interesting paper *Human Law and the Laws of Nature* (1951), Needham suggests that the concept of a divine legislator, absent in China, may have been necessary for the genesis of the idea of "laws of nature", and also for Western confidence that the secrets of a cosmos ordered by a rational being will be intelligible to rational beings. We no longer think of the phrase "laws of nature" as anything but a metaphor, but "the problem is whether the recognition of such statistical regularities and their mathematical expression could have been reached by any other road than that which Western science actually travelled".[8] Here of course we are at the

[7] GT 150.
[8] GT 330.

crux of the matter. As with most if not all answers to the negative question we can think of alternative routes; and the trouble is not that they are plausible but that we can neither estimate their plausibility nor set limits to their proliferation. On the present issue one can come to closer grips with Needham by doubting the relevance of a divine legislator to cosmic rationality even in Europe. Since Zeus gave laws only to gods and men, the Greeks should have had rather less grounds for faith in a rational universe than the Chinese, whose Heaven, however impersonally conceived, commands nature as well as man by his *ming* 命 "decree". Nothing discourages Christians from stressing the incomprehensibility of a transcendent God rather than the rationality of his works, depending on how much of the Greek they have in them. But on the issue of laws of nature we are again trapped in the kind of debate in which one side suggests that there was no possibility but the one actualized and the other side produces speculative alternatives. The Neo-Confucian cosmos was rational in the sense that it interpreted the Heaven which one obeys and the Way that one walks as *li* 理, the pattern or layout of things, within which, wherever we discern a local arrangement, we can infer (*t'ui* 推) from one case to another. The Neo-Confucians identified *li* with the decree of Heaven and might conceivably have built a legislative metaphor on this basis, but it is difficult to see why they would need it. They were interested in laying down general principles, moral, political and also natural, which they presented as *li*; if they had ever reached the point of formulating principles in mathematical terms and testing them by experiment, the concept of the myriad *li* which go back to one *li* would surely have provided a sufficient theoretical framework. Needham, always meticulous in collecting the relevant facts, admits that the use of the term "law" did not really catch on until after Galileo, who had spoken instead of "proportions", "ratios", "principles".[9]

This is not to deny the importance of a divine legislator in the European development. Indeed the significance of God as designer of the clockwork is clear in seventeenth and eighteenth-century science, which inclined even after diverging from official religion to deism rather than to atheism. If there is a personal Creator, the universe is not simply there (as for Aristotle) and has not simply grown (as for the Chinese), but has been designed and constructed, so that the way to understand it is to take it to pieces like a man-made instrument and see how it works. This implies that nature is comprehensible in a special way, narrower than its rationality for the Greeks or the universality of *li* in Neo-Confucianism. Indeed the kind of rationality which seems to be guaranteed by a divine order is partly repudiated by modern science. It denies that there are reasons for coincidences; if asked how some rare conjunction can be explained except as a

[9] GT 307. For a fuller treatment of laws of nature written in 1956, cf. SCC 2/518–84.

warning omen, or how to account for a cruel accident without imputing injustice to God, it absolutely refuses explanation. What it requires is the treatment of a hypothesis about nature after the analogy of an instruction how to build a model, which justifies itself only when tried out, and can be tried out only if it includes exact measurements. The existence of the divine artisan authorizes the universalization of the viewpoint of the artisan, whose practice, as Needham notices elsewhere,[10] united mathematics and experiment long before 1600 but took a long time to make an impression on theory because the thinking classes do not soil their hands.

Would the absence of a Creator in Chinese thought prevent such a development? In China we find only the idea of impersonal *shen* 神 "spirit, the numinous, the divine" as the power behind the *tsao-hua* 造化 "the productive process", the process of nature by which things develop, and of a "maker of things" (造物者) who is a consciously poetic personification. But it is interesting to notice how easily Chinese writers fall into this kind of language when admiring constructed models of nature such as automatic toys[11] and armillary spheres. The artificial man in a well-known story in *Lieh-tzŭ* 列子[12] who seems human until taken to pieces, excites the comment: "Can man's skill then share the achievement of the author of the productive process?" (人之巧乃可與造化者同功乎). The *Chin shu* 晉書, after describing how the rotation of an armillary sphere made by Chang Heng about A.D. 140 fitted the rotation of the heavens like two halves of a tally, quotes the panegyric: "His mathematics comprehended heaven and earth, his workmanship equalled the 'productive process', his high talent and glorious art exactly coincided with the Divine." (數術窮天地，制作侔造化，高才偉藝與神合契).[13] The use of such language rouses one's curiosity as to whether it occurred to anyone that man can infer how nature itself works from how his own constructions work. There is in fact a remarkable example in the comment of Chang Chan 張湛 (*c.* A.D. 370) on the *Lieh-tzŭ* passage:

> 近世人有言人靈因機關而生者。何者。造化之功至妙，故萬品咸育，運動無方。人藝麤拙，但寫載成形，塊然而已。至於巧極，則幾乎造化。
>
> Recently there have been people who say that human sentience is generated through a mechanism. Why? The achievements of the "productive process" are extremely subtle, therefore the myriad varieties are all fostered and their activities are boundless. Man's arts are crude

[10] SCC 3/158.

[11] For the kind of toy automata which presumably inspired the *Lieh-tzŭ* story of the artificial man and its parallels in other cultures, cf. SCC 4, Part 2/156–65.

[12] *Lieh-tzŭ* (*Ssŭ-pu Ts'ung-k'an* 四部叢刊) 5/7 AB.

[13] *Chin shu* (*Pai-na* 百衲) 11/3B/7.

and clumsy, and all they can do is reproduce[14] already developed shapes in a rough way. But if human skill were perfected, it would hardly fall short of the "productive process".

Chang Chan rejects the idea and asks: "How can it mean that a thing does not have a spirit in control of it?" (豈謂物無神主邪). The interest of the passage is its suggestion of a conceptual framework suitable to the development of modern science. Given an inquirer who sets out in earnest to show that something in nature works in the same way as its artificial model (such as the heart working like a pump) he would find himself drawn into measurement and experiment.

Time and Eastern Man (1964), a particularly brilliant examination of the Chinese sense of time ranging from historiography to clocks, is included in the volume for the sake of its discussion of the common claim that the cyclic time of Greece and India turned attention from the future while Christian eschatology encouraged a hope secularized in the doctrine of Progress. Needham argues that much Chinese thought about time conceives it as linear rather than cyclic, so that the problem has nothing to do with the failure to achieve modern science. The supposed links between the Scientific Revolution and conceptions of time are in any case so tenuous and involve so many imponderables that he offers only tentative suggestions.[15] I must confess to a personal inability ever to understand why the Hindu is supposed to be paralysed by the knowledge that no human achievement can outlast a kalpa of 4,000,000,000 years, while the Christian, cramped inside a time scheme of a few thousand years from Creation to Judgement, works hopefully at sciences which have nothing to do with his salvation in the knowledge that the Last Day may already have dawned.

With regard to internal factors in the development of science, Needham shows that practical experiment without the refinement of experimental methods is common to China and medieval Europe, and that in mathematics China was strong in algebra but weak in geometry. He estimates that in the thirteenth and fourteenth centuries, Chinese algebra was the most advanced in the world.[16] But the mathematics of modern science required from the beginning the entire Arabic inheritance, not only the decimal place value system and algebra, but the geometry of the Greeks. All this passed to Europe with the Arabic–Latin translations but did not reach China, although here there is a fascinating example of an historical near-miss; the Mongols brought Muslim astronomers with Arabic books, and there is evidence of a translation of Euclid in the Imperial library in 1273,[17] but this knowledge never attracted attention or passed into general circulation.

[14] Mistranslated at this point in my *Book of Lieh-tzŭ* (London, 1960), 111.
[15] GT 292.
[16] GT 44. For the Sung algebra, cf. SCC 3/38–53.
[17] SCC 3/105.

The mathematics developed in Europe after 1550 was an application of algebra to geometry, and Derek Price has examined an earlier nodal point in the history of science, uncovered by the researches of O. Neugebauer, at which Greek geometry had already proved itself essential.[18] The crucial discipline in the development of modern science was astronomy, which even at the stage of the most primitive calendar-making combines mathematization with testing (of course by observation and not by experiment); and the most important advance in mathematization before the sixteenth century was the application of geometry to astronomy by the Hellenistic school which culminated in Ptolemy (*c.* A.D. 140). Behind this was the meeting of two independent traditions, Greek geometry and Babylonian astronomical observations and arithmetical computations, in Hellenized Mesopotamia after 300 B.C. (The Greeks had been weak in arithmetic as well as in astronomy.) This event, which we now see to have such decisive significance, bore no further fruit for nearly a millennium and a half, until the renewed application of geometry to astronomy by Copernicus and Kepler in the sixteenth century, followed almost at once by fusion with experimental methods. In China, as Nathan Sivin shows,[19] mathematical astronomy came to a dead end in arithmetical systems of interrelated time-cycles, and interest in them soon waned as the hope was lost of reconciling them with observation. Only in the last creative phase of Chinese astronomy, the Sung (960–1279), is there some tendency to apply geometry and conceive physical models.[20] Needham quotes a letter in which J. D. Bernal identifies the absence of an adequate geometry to apply to astronomy as the basic weakness of Chinese science.[21] Needham is not much impressed, being more interested in external than in internal factors. We may notice, however, that this is an example which shows up particularly clearly what is involved in comparing the Chinese and Western traditions. We can examine the route by which the West arrived at the Scientific Revolution and show that China was not taking this route. But unless we wish to entangle ourselves in a demonstration that modern science could only have begun in the field of astronomy, could never have made its take-off with laws statable in terms of traditional Chinese mathematics, only afterwards refining its geometry to deal with astronomy, we are not even talking about the negative question which is supposed to be so important, "Why was there no Scientific Revolution in China?" The question may also be raised whether Ptolemy or even Copernicus and Kepler were in principle any nearer to modern science than the Chinese and the Maya, or indeed than the first astronomer, whoever he may

[18] Price (as n. 4), 1–22.
[19] N. Sivin, "Cosmos and Computation in early Chinese Mathematical Astronomy", *T'oung Pao*, 55 (1969), 1–73.
[20] Sivin (as n. 18), 67, 68, 70–3.
[21] GT 42.

have been, who allowed observation to outweigh numerological considerations of symmetry in his calculations of the month and the year. Astronomy seems to have been a mathematized discipline in which numerology was at war with observation from its very beginnings up to Kepler himself; the importance of geometry (apart from its general importance to the sciences as a model of demonstration) was merely as a tool to carry astronomy beyond a certain point of development.

A general consideration which will occur to anyone comparing Chinese and Western thought is the much greater intellectual stringency of the latter. Granted that it is arbitrary to include Greek logic itself under the heading of scientific explanation, the importance of Greek rationality in the ancestry of modern science is not in doubt. The quality of Chinese argumentation varies with the extent of division and controversy, and never returned to the height that it attained in the third century B.C. at the very end of the period of the competing Hundred Schools. Needham quotes the observation of H. O. H. Stange that the Greek philosopher debates with equals by logical disputation, the Chinese advises a prince with the support of historical precedents.[22] (Is it perhaps symptomatic of Needham's commitment to China that he uses the quotation not to criticize Chinese thought but to rebut the curious claim that only Europe has a sense of history?) It may be noticed that here the difference is one of degree, so that for once the positive and negative questions do come together; to the extent that the logical prowess of the West was a precondition of the Scientific Revolution, the relative weakness of China explains its failure. However, people who ask why China never discovered the scientific method are hoping for rather more than a vague consideration which suggests that Europe would have a better chance than China. Is it possible to find some difference in kind between traditional Chinese thinking and that required by the Scientific Revolution?

The transient first impression of a fundamental strangeness, a difference in kind, does not survive a prolonged study of Chinese thought. The Chinese weigh practical advantages and disadvantages, perceive and utilize analogies, concentrate their insights in aphorisms, fascinate themselves with numerical symmetries, and sometimes reason analytically, very much as we do; if we find their thought difficult it is because of unnoticed differences in underlying concepts and in the implicit questions behind their inquiries. What we do miss, as Nathan Sivin observes, is "the notion of rigorous demonstration, of proof".[23] This concept of proof, it may be necessary to insist, is narrower than any vague idea of "Reason" which could be supposed to characterize Western thought in general. Even in the West it requires quite a special temperament to appreciate the full value of the geometrical

[22] GT 243.

[23] "How does science begin?", letter in *Technology Review* (December 1968), 69.

proofs we learn as schoolboys, demonstrations which are so far in excess of the ordinary demands of common sense. Intelligent people who do not share this temperament often positively mistrust and dislike it, whether from the point of view of religious faith, of romantic intuition or of Anglo-Saxon empiricism. Nor is the concern for rigorous proof equivalent to an interest in logic for its own sake. The fathers of the Scientific Revolution were interested in demonstration, not the logical forms of demonstration; their contempt for logic as a discipline in fact made the period from the fifteenth to the early nineteenth century a veritable Dark Age in the history of logic, which supposed, as befits a Dark Age, that the edifice was completed by Aristotle, and forgot the advances of Stoics, Arabs and scholastics which research is now rediscovering.[24]

It is therefore hardly profitable to make the vague accusation that Chinese thinkers lack our respect for reason, or to stress that even the later Mohists, who did study certain types of valid and invalid argument, never abstracted necessary forms like the Greek and Indian syllogism. What matters is that most Chinese thinkers (like ourselves, in most of our thinking outside the exact sciences) exchange arguments of varying and indefinite weight without seeing any point in putting premises and conclusion in the same form, filling in all steps however obvious, and pressing every line of thought to its logical end. In particular the Chinese never developed geometrical proofs like those of Euclid, which served as the model for the demonstrations in physics of Archimedes and of the founders of modern science. But although the ideal of rigorous demonstration has had lasting effect only in the Greek, Arabic and Western cultures it certainly emerged at least once in China, among the sophists and Mohists of 350–200 B.C. We may instance the refutation of an objection to the Mohist doctrine of universal love, which illustrates the meticulousness with which later Mohists try to put premises and conclusions in the same form, make all logical steps explicit, and delimit what they claim to prove (in this case, merely that a position cannot be "treated as certain" or "is free from difficulty").

Mohist Canons B 73 無窮不害兼。說在盈否。

南者有窮則可盡，無窮則不可盡。有窮無窮未可智則可盡不可盡[不可盡]未可智，人之盈之否未可智，而[必]人之可盡不可盡亦未可智，而必人之可盡愛也誖。

人若不盈(先)* 無窮則人有窮也，盡有窮無難。盈無窮則無窮盡也，盡(有)* 無窮無難。

Canon "There being no limit is not incompatible with something being done to all of it. Explained by: whether it is filled or not.

[24] Cf William and Martha Kneale, *The Development of Logic* (Oxford, 1962), 298–378. N. Rescher, *Studies in the History of Arabic Logic* (Pittsburgh, 1963).

Explanation (Objection) If the South has a limit it is exhaustible, if it has no limit it is inexhaustible. If whether it is limited or not is not yet knowable, then whether it is exhaustible or not is not yet knowable, whether men fill it or not is not yet knowable, whether men are exhaustible or not is likewise not yet knowable, and it is erroneous to treat it as certain that men can be exhaustively loved.

(Answer) If men do not fill the limitless then men are limited, and there is no difficulty about exhausting the limited. If they do fill the limitless then the limitless has been exhausted, and there is no difficulty about exhausting the limitless."

As for the Chinese language, Needham is content to expose the fallacy that the script, mistakenly supposed to be not logographic but ideographic, would inhibit abstract thought, and to point out that the exposition of twentieth-century science in Chinese has presented only the problem common to all languages of evolving a technical terminology.[25] I have myself argued elsewhere that claims that Chinese thought is hampered by confusions over distinctions marked by Indo-European number and case always break down when a concrete instance is offered, but also that the discovery of logic as an independent discipline (a dispensable luxury for the Scientific Revolution, as we have just noticed) may be easier in an inflected than in an isolating language. [26] Logically the advantage of an inflected language is that the changing word forms illuminate the structure of the sentence, an advantage which has nothing to do with the supposed utility of the distinctions marked, which may be quite irrational (as with gender). The structure of an isolating language is invisible without the aid of modern linguistics and offers no foothold for an exploration of grammar or logic; it allows any degree of exactness or inexactness, so that the vagueness or precision of Chinese thinking must always be attributed to extra-linguistic factors. The sharpening philosophical controversies of the fourth and third centuries B.C. involved a clarification of terminology and tightening of syntax in some ways comparable with the effects of science on contemporary Chinese. For example, because of problems raised by controversy over their doctrine of universal love the later Mohists were interested in quantification of the object, and they defined two of the quantifiers (盡, 莫不然也 "'All' is 'none not'", 或, 不盡也 "'Some' is 'not all'"). In the service of this concern they regularize the grammar of the distributives. To refer back to the subject they use *chü* 俱 "all", *huo* 或 "some", *mo* 莫 "none", to refer forward to the object *chin* 盡 and the patterns 有, 無 . . . 於 . . . (有愛於人 "love some men", 無遺於其害

[25] GT 37–39.

[26] "The Logic of the Mohist *Hsiao-ch'ü*", *T'oung Pao*, 51 (1964), Part 4 "The Mohist Logic and the Chinese Language", 39–53.

也 "overlook none of the harm in it"). In other constructions for which the the last formula could be mistaken confusion is avoided by using *huo-che* 或者 *wu* 毋 and the preposition *hu* 乎 (或者遺乎其問也 "Some are overlooked by his question", 心毋空乎內 "the heart has no hollow inside it"). In the language of late Mohist dialectics, vocabulary is regularized (a fact obscured by great graphic variety due to imperfect adaptation of graphs to later usage), there are virtually no synonyms among particles, idiom is avoided, syntactic consistency is observed even at the cost of sentences so extraordinary that they have generally been taken to be corrupt (有有於秦馬" have some Ch'in horses").[27] Given the extra-linguistic conditions for the emergence of modern science the Chinese language would presumably have adapted itself much as seventeenth-century English allowed itself to be reformed by the Royal Society.

An important point of Needham's, further developed in *Science and Civilization in China*,[28] is that medieval science or proto-science with its Galenic humours in Europe and Yin and Yang and Five Elements in China is culture-bound, but from the point that science is mathematized and experimentally testable it acquires the cultural universality of mathematics and logic. There is nothing in our culture which carries so openly the marks of its Oriental origin as the numerals that we still call "Arabic" in contrast with "Roman", or the concepts which still bear Arabic names – algebra, zero, zenith, nadir, chemistry – but since they belong to culture-free disciplines we do not feel them to be alien at all. There is no reason to assume that the world will keep for long its feeling that modern science is specifically Western. The geographical region where modern science began remains important only as long as it keeps the initial advantage of having been the discoverer, afterwards presumably will concern historians alone, like the origin of agriculture in the Middle East and, within the already industrialized world, the origin of industrialism in England. To think of the modernization of Asia and Africa as their "Westernization" in any but a short-term sense is to forget that the Industrial Revolution disrupts and transforms all preceding cultures in West and East alike, and at the same time throws their resources into a common pool. It is possible to wonder whether we ourselves will necessarily be classed as belonging to "Western civilization" by historians of the not so far distant future. They may find it more convenient to treat the West as the first of the great agrarian civilizations to lose its identity after the Industrial Revolution. If we knew more about the tribes which first settled on the banks of the Nile we might find cultural continuities comparable to those between medieval Europe and ourselves, but we should not be tempted to regard the revolutionary change to agriculture as

[27] For the references cf. Graham (as n. 24), 6, 11–14.

[28] GT 15, 16; SCC 3/447–51.

a mere episode in an Egyptian tradition. Such assumptions of a surviving homogeneous culture as that a Westerner whatever his overt beliefs has a sensibility rooted in Christian symbolism which allows only a superficial conversion to Vedantism or Buddhism, and a coherent artistic heritage from the Renaissance which admits Oriental influences only at the level of the picturesque, no longer seem self-evident as they did even a generation ago. The whole European and Middle Eastern conception of religion as the pursuit of moral improvement in the service of a personal and transcendent God seems to come less and less naturally to the spiritually hungry even when they are professing Christians, which suggests as profound a break in a cultural succession as it would be possible to conceive. However we may judge the alien contributions during the last century and a half to every aspect of our culture outside the immediate reach of science, from Schopenhauer's debt to the Upanishads to the Black American and now African and Indian elements in popular music, it is already obvious that more is involved than the mere exoticism of eighteenth-century chinoiserie. The Japanese woodblock for the Impressionists and Japanese architecture for Frank Lloyd Wright, Chinese poetry for the Imagists and African sculpture for Picasso, were active influences at crucial moments in the development of major modern styles.

It is not altogether easy to break the habit of thinking of History as blindly groping towards a goal which the West alone was clever enough to reach, and Needham himself sometimes has the air of making allowances for the Chinese and offering compensations. But the only conscious goal which anyone has been able to find in the social processes which led to the Scientific Revolution is capitalist profit. Accidents such as Greek geometry encountering the Babylonian astronomy which it was to transform, or China (which had the astronomy) developing not geometry but algebra, are hardly to the credit or discredit of a civilization. When we consider how slowly both the West and China have responded to alien discoveries as long as they were confident of their own cultural superiority (the Indian numerals adduced by the Syrian bishop Sebokht in 662 as proof that the Greeks do not know everything but their use in Europe unattested until 976; Euclid unnoticed in China until the Jesuit translation of 1607 although apparently available from Muslim astronomers as early as 1273)[29] we can see a direct connexion between the superiority of the West about 1600 and its abject inferiority about 1000, which forced it to borrow the Arabic sciences wholesale and thus become the possessor of the all-important combination of Greek and Indian mathematics. Is it necessary to say more than that one set of conditions for the genesis of modern science came together in sixteenth-century Europe, and that since it spread too fast to allow independent

[29] SCC 1/220; 3/146, 52, 105.

occurrence elsewhere this is the only set of conditions of which we can ever know? The tremendous dynamic of the Scientific Revolution distinguishes it in this respect from the only comparable event in history, the Neolithic invention of agriculture and the ensuing urban revolution in the Middle East. Agriculture continued to spread through the millennia between the natural barriers of the Atlantic and Pacific, so that there could be time and space for its independent discovery elsewhere. But the few centuries of the spread of modern science, although long in terms of its own accelerated time scale, are short in relation to the slow rise and fall of agrarian civilizations.

Nathan Sivin begins his recent book on Chinese alchemy[30] with the observation that to ask of Chinese science "Why did it not spontaneously evolve into modern science?" is a question best postponed until more is known. But he does not doubt its importance:

> This question to be sure, is crucially important, for much of China's convulsive experience of the past century or so and, indeed, much of her predictably convulsive experience of decades to come are part of a world upheaval in which intellectual, social and economic consequences of the Scientific Revolution are gradually asserting themselves.

But here we are concerned with something different, the factors in Chinese society and culture favourable or unfavourable to the assimilation of industrial civilization in all its aspects, and the problem of origins is left behind. If we imagine sixteenth-century Europe invaded from outside by electronics and plastics, air travel, nuclear energy and napalm, television and pop music, its struggle to adapt would not be eased by being itself on the verge of the discovery of quantitative physical science. Whatever China's problems, absence of conditions in which mathematization could combine with controlled experiment is no longer one of them. That tradition of centralized bureaucracy which according to Wittfogel and Needham inhibited the growth of the merchant class and therefore of science may have turned to China's advantage, since as soon as science is visibly a means to power a state's fear of more modern states becomes a stronger motive for importing it than commercial profit. The un-Chinese concept of a divine legislator or watchmaker has long ago lost its utility. Needham himself has often emphasized that a tendency toward organic rather than mechanistic thinking, although it conflicted with the pre-suppositions with which modern science began, may facilitate the assimilation of twentieth-century science. Here one is again reminded of the difficulty of throwing off the assumptions of the old vague question "Why did China fall behind?", even when the issue has narrowed to the presence or absence of

[30] Nathan Sivin, *Chinese Alchemy: Preliminary Studies* (Cambridge, Mass., 1968), 1, 2.

certain conditions immediately preceding Galileo. If the historians of science are right in so concentrating the issue, the setting of the Scientific Revolution in Europe becomes a matter of particular conditions, some persistent (such as the habit of philosophical and theological logic-chopping) and others transient, and we can no longer assume that outside them Western civilization in 1600 was any less remote than China from a civilization already revolutionized by modern science. It is irrelevant that the conflict between traditional culture and the Scientific Revolution has been so much weaker in the West than elsewhere. The civilization in which the scientific method is first discovered will have only the problem of adapting to the Scientific Revolution itself; all others must adapt also to the alien civilization from which it reaches them, which is less and less like themselves or any other agrarian civilization, including the Europe of the past.