litical—by the advent of the theory of evolution." Yet he sees "pure chance, absolutely free but blind, at the very root of the stupendous edifice of evolution." In the concluding paragraph of the last chapter he states: "man knows at last that he is alone in the universe's unfeeling immensity, out of which he emerged only by chance." "Chance" is a slippery word that must be used with care when applied to evolution. There are two kinds of "chanciness," or randomness, in the process of mutation. First, alterations in the hereditary materials arise by accidental substitution, addition, or deletion of nucleotides in the DNA of the genes, or of the gene complexes in the chromosomes. Second, mutations occur regardless of whether they are useful or harmful to the organisms that inherit them. It does not follow that any gene can be transformed into any other gene by a single mutation; though a gene can be changed in many ways, the repertoire of possible mutations in a gene is limited by its composition, which is in turn a product of its evolutionary history. Thus a gene coding for hemoglobin cannot mutate into one coding for myoglobin, although these genes are remote descendants of the same ancestral gene.

The process of mutation is the source of the raw materials for evolution. A supply of raw materials for a building is, however, not a building, and it does not by itself guarantee that a building will be built. Evolution occurs when mutational materials are compounded by natural selection into adaptively coherent genotypes. This is the source of the internal teleology which Monod rightly regards as a distinctive property of living beings. He acknowledges the fundamental importance of natural selection in evolution, but underestimates its antichance function. Selection is far more than a sieve which retains useful mutants and disposes of harmful ones (the "sieve analogy" is not mentioned by Monod, but that view is implicit in his discussion). Mutation and Mendelian recombination, the latter being a corollary of sexual reproduction, bring forth an immense variety of different genotypes, the numbers of which are in higher organisms almost as great as the numbers of individuals conceived. Mutation and recombination link with selection to form a cybernetic system that maintains or enhances the internal teleology, that is, the harmony between a living species and its environments. Disruption of this system results in eclipse or extinction of the species.

Neither mankind nor any other biological species evolved by pure chance. Yet it does not follow that they were predetermined to arise. Monod rightly stresses that in evolution "destiny is written concurrently with the event, not prior to it. Our own was not written before the emergence of the human species, alone in all the biosphere to utilize a logical system of symbolic communication." Yet Monod stops short of concluding that we are the products neither of chance alone nor of pure necessity. In biological evolution, and also on the human level, chance and necessity are not the two horns of a dilemma; natural selection blends them in a unique creative system. No more than remote analogues of this system are found in the nonliving world, but analogues are common on the biological and the human levels. Did Beethoven create the *Eroica* by chance or out of necessity? The majestic march of biological evolution resembles human creativity more than it does the hazards of roulette, and this in the face of the fact that natural selection is a "blind" agent which cannot foresee the future needs of a species on which it operates.

The anchor of Monod's world view is "that nature is objective, that the systematic confronting of logic and experience is the sole source of true knowledge." It is this idea that "wrote an end to the ancient animist covenant between man and nature, leaving nothing in place of that precious bond but an anxious quest in a frozen universe of solitude." It also "prohibits any confusion of value judgments with judgments arrived at through knowledge." Yet the principle of objectivity is in itself "the ethic of knowledge," and Monod sees in this ethic the foundation of man's future development. A most inspiring and noble view, but in this short book the author is unable to come down to specifics. How can the ethic of objective knowledge be applied to the everlasting problems of good and evil, or to the particular problems which mankind faces at present? Monod does mention that it can provide "the moral inspiration for a really *scientific* socialist humanism" but does not explain what this socialism will be like. In conclusion, let me say that, despite some fairly major disagreements, no recent book by a biologist have I found more fascinating and thought-provoking.

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Construction and Invention

Science and Civilisation in China. Vol. 4, Physics and Physical Technology. Part 3, Civil Engineering and Nautics. JOSEPH NEEDHAM, with the collaboration of Wang Ling and Lu Gwei-Djen. Cambridge University Press, New York, 1971. lviii, 932 pp., illus., + foldout maps. $55.

No appropriate words can be found to describe the enormous energy and wide-ranging erudition which mark the works of Joseph Needham. A biochemist in his own right, Needham took an interest in Chinese culture and learned Chinese under his own steam. His appointment as the leader of the British scientific mission to China during the Second World War marked the beginning of his seven-volume project on science and civilization in China, of which three more volumes, in five tomes, are still to come. Meanwhile, as by-products of this project, Needham has published a number of important smaller works, most recently *The Grand Titration: Science and Society in East and West* (1969) and *Clerks and Craftsmen in China and the West* (1970).

The present volume, dealing with civil engineering and nautics under the general heading of Physics and Physical Technology, constitutes the third and final part of volume 4. Sheer bulk demands the separation into parts for "comfortable meditative evening reading." The volume, like its predecessors, is well produced and extremely generous with Chinese characters and illustrations. The illustrations alone, of which there are over 300, are a veritable record of the achievements of traditional Chinese technology, and when they are juxtaposed with examples from Europe (for example, bridges, ships, cartography) and the rest of the world (for example, types of sails), their comparative value cannot be denied. In many cases, lengthy and instructive comments accompany the illustrations.

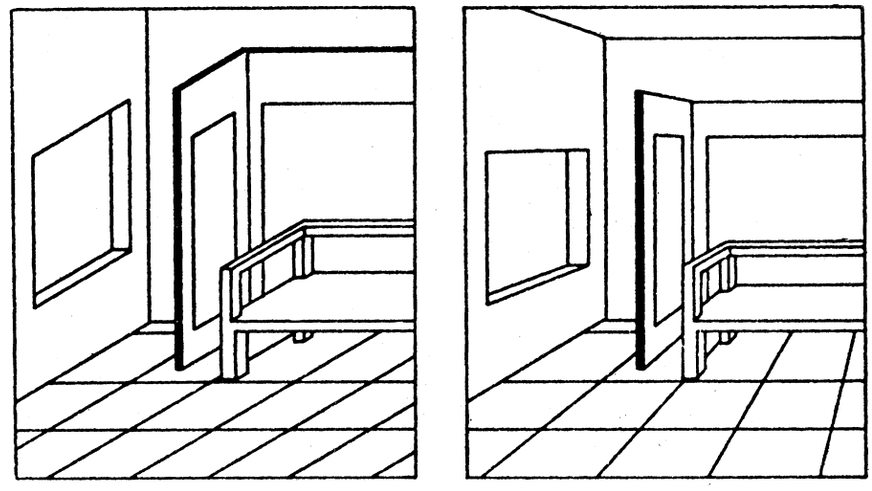
In the vein of his previous works, Needham again emphasizes the importance of understanding Chinese science within the Chinese frame of reference. Chinese drawing, for example, has often been criticized as being unable to represent distance. Needham tells us that this is by no means the case. The criticism arises only because the Chinese, in the absence of Euclidean geometry and the post-Renaissance science of optics, had to resort to different conventions such as the "parallel perspective" to represent distance (see illustration). Once this is understood, Chinese "work-

ing drawings" will become meaningful.

There is no doubt that one of Needham's major aims is to put Chinese scientific achievements in their proper place in a universal context. Comparison thus becomes one of his basic approaches, and in the process of comparison achievements in similar fields in Europe, the Arab world, and India are underscored. His work is therefore integrative although it also betrays a partiality toward the Chinese. The present volume adds many more items to the already impressive list of Chinese "firsts." Segmental-arch bridges were constructed in China in the 7th century, whereas in Europe they did not appear until the 13th. When the first iron-chain suspension bridge was constructed in Europe in 1741, it was 12 centuries behind the Chinese. The watertight compartment in marine engineering was introduced in Europe after an even greater delay, at the end of the 18th century. The Chinese were also much earlier in the construction of contour transport canals and transport canals parallel to a navigable river. Sophistication in the art of navigation and superior ships enabled the Chinese to sail on East African waters almost a century before the first appearance of the Portuguese. These examples can be multiplied several times.

Needham maintains that Chinese technological influence came to Europe in "packages" from time to time, although the exact manner in which the transmission was made cannot always be established with certainty. If the same discovery or invention appeared at different times in different parts of the world, he insists that the onus of proof lies upon those who wish to maintain that development was independent. On the other hand, he does admit that many techniques introduced in Europe were afterward better developed there than in China. The question then arises: Why were the Chinese unable to maintain their supremacy after the 16th century? This is the question Needham intends to deal with systematically in his last volume (the seventh). The present volume, however, provides several clues.

In the first place, there existed in traditional Chinese society a vast gap between the literati, who were culturally adverse to science in its pure or applied form, and the artisans, who were mostly ill educated if not illiterate. But Denis Twitchett has suggested that the gap between the two groups was considerably narrowed particularly during the Han and the Sung dynasties, thus accounting for the relatively rapid development in technology in those periods. Furthermore, the character of the literati did not always remain the same, especially after the extensive use of the examination system from late T'ang on. These are the problems to which Needham must address himself in his final conclusion. Second, the Chinese had a propensity to rely heavily on pilot projects and commonsense balancing of weight in lieu of systematic theorization. And finally, in some instances, technical objects were quickly transformed into objects of art, as in the case of architectural models which were turned into objects of interior decoration. The original function somehow vanished, but Needham does not explain.



Diagrams showing the difference between (left) Chinese "parallel perspective" or axonometric drawing and (right) convergent or optical perspective. [From *Science and Civilisation in China*, vol. 4, part 3, p. 113; redrawn from B. March, "A note on perspective in Chinese painting," *China Journal of Science and Arts* **3**, 113 (1931)]

In the section on hydraulic works, a contribution is made to the theory of hydraulic society as expounded by Karl Wittfogel. In Ceylon, despite the impressive achievements in hydraulic engineering, no permanent bureaucratic or despotic society after the Chinese model developed. Needham ascribes this to the fact that the hydraulic works in Ceylon were basically irrigational and, once begun, needed little continuing effort. In China, major hydraulic works were designed for water control purposes and required constant repair and improvement, leading to a highly bureaucratic society. However, a recent study by H. G. Creel suggests that the methods of bureaucratic rule (itself a contribution to world civilization if one wishes to plug Chinese achievements) were developed even earlier than the appearance of major water control projects. Whether or not Creel's theory is tenable, it provides food for further thought.

For the sinologists, Needham and his Chinese collaborators' greatest contribution is in the history of Chinese science, many aspects of which are given systematic treatment here for the first time in any language. The survey of source materials that precedes the account of each subject will prove to be of great value for serious scholars. However, there is undeniably a reluctance on the part of Needham and his collaborators to weave Chinese science and society into a comprehensive whole. For example, was the sudden burgeoning of megalithic beam bridges in Fukien in the 11th to the 13th centuries the result of an unprecedented growth in maritime trade? An answer to this and similar questions will shed much light on the mutual impact of science and society in traditional China. (Indeed, government apart, who "funded" Chinese science?)

In a work of this magnitude, some drawbacks are unavoidable and should not obscure the fact that the present volume represents an important contribution to the field of Chinese science and technology. The book is well written, and despite its heftiness and technical nature makes comfortable meditative evening reading. Mammoth bibliographies (130 closely printed pages) of Chinese, Japanese, and Western works conclude the volume.

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