6. HERRINGTON, L. P. *Am. J. Physiol.,* **129**, 123 (1940).
7. SWANSON, G., and EVANS, C. *J. Mammal.,* **17**, 39 (1935).
8. WISLOCKI, G. B. *Quart. Rev. Biol.,* **8**, 385 (1933).
9. WADE, O. *J. Mammal.,* **11**, 160 (1930).
10. HARTMAN, F. A., BROWNELL, K. A., and CROSBY, A. A. *Am. J. Physiol.,* **98**, 674 (1931).
11. MARTIN, S. J., and MARESH, F. *Ibid.,* **105**, 271 (1933).
12. BENEDICT, F. G. *Carnegie Inst. Wash. Pub. No. 503* (1938).
13. BRITTON, S. W., and KLINE, R. F. *Am. J. Physiol.,* **125**, 730 (1939).
14. GELLHORN, E., and JANUS, A. *Ibid.,* **116**, 327 (1936).
15. OLITSKY, L., AVERING, S., and KOCH, P. K. *J. Immunol.,* **45**, 237 (1942).
16. SIMPSON, S., and GAILBRAITH, J. J. *J. Physiol.* (London), **33**, 225 (1905).
17. UNDERHILL, F. P., and POLK, G. T. *Am. J. Physiol.,* **66**, 519 (1923).
18. JACKSON, F. K., and ALONGE, A. *Ibid.,* **109**, 447 (1934).
19. LEE, R. C. *Ibid.,* **125**, 521 (1939).
20. DUKES, H. H. *The Physiology of Domestic Animals.* Ithaca, N. Y.: Comstock Pub. (1947).
21. KOLMER, J. A. *Approved Laboratory Technique.* New York: Appleton-Century (1945).
22. FRIEDMAN, M. W. F., and BENNETT, I. F. *Federation Proc.,* **2**, 13 (1943).
23. KIRK, H. *Index of Diagnosis for the Canine and Feline Surgeon.* Baltimore: Williams & Wilkins (1947).
24. ANON. *Life,* **28**, (2), 91 (1950).
25. BENEDICT, F. G. *Carnegie Inst. Wash. Pub. No. 474* (1936).
26. ———. *J. Mammal.,* **19**, 175 (1938).
27. ZENKOVICH, B. A. *Doklady Akad. Nauk SSSR,* **18**, 685 (1938).
28. MARTINE. *Essays Medical and Philosophical,* 335 (1740); In HERMANN, L. *Handbuch Physiol.* (Leipzig), **4**, 318 (1880).
29. HANNA, G. D. *Am. J. Physiol.,* **68**, 52 (1924).

Book Reviews

The Exact Sciences in Antiquity. **O. Neugebauer. Princeton, N. J.: Princeton Univ. Press, 1952. 191 pp. and 14 plates. $5.00.**

Despite all the lip service given nowadays to general education, rarely is science assigned more than a minor technical role of "information, please." Any integration of science with culture is supposedly the responsibility of self-styled humanists, who rely primarily upon the scholarship of other humanists. It is not surprising, therefore, that the historical interrelationships between science and civilization are somewhat distorted. What is needed as a basis for any generalizations are researches by scientifically trained historians and/or by historically trained scientists. Otto Neugebauer belongs to this class. As he gratefully remarks in the preface, with respect to its dedication to Richard Courant: "I owe him the experience of being introduced to modern mathematics and physics as a part of intellectual endeavor, never isolated from each other nor from any other field of civilization."

The present book, a modified form of the author's 1949 Cornell University "Messenger Lectures on the Evolution of Civilization," is a semipopular, scholarly account of mathematics and astronomy in Babylonia and Egypt in their relationship to Hellenistic science. It is based upon the author's belief that "The investigation of the transmission of mathematics and astronomy is one of the most powerful tools for the establishment of relations between different civilizations." The author modestly concludes his account with the remark: "Perhaps it is vain to hope for anything more than a picture which is pleasing to the constructive mind when we try to restore the past."

After a review of the early history of number symbols, the author discusses the characteristic features of mathematics in the Old Babylonian period of the Hammurabi dynasty. To an amateur, such as myself, nurtured upon classical tradition, it is startling to learn of the highly developed numerical skills utilized at this time. Tables still exist containing squares and square roots, cubes and cube roots, and sums of squares and cubes. Special types of cubic equations were solved; particular exponential functions (for the computation of compound interest) were used; arithmetical progression was known. From a Seleucid text one finds "the correct application of the 'quadratic' formula for the solution of quadratic equations."[1] Their computed value of 1.414213 (actually 1.414214) for the square root of 2 was still used by Ptolemy. In connection with such numerical work, "The determination of the diagonal of the square from its side is sufficient proof that the Pythagorean theorem was known more than a thousand years before Pythagoras." Even the "fundamental formulas for the construction of triples of Pythagorean numbers were known. . . . Geometrical concepts play a very secondary part in Babylonian algebra."

After this fascinating revelation of "a level of mathematical development which can in many aspects be compared with the mathematics, say, of the early Renaissance," it is somewhat of a letdown to read about the status of early Egyptian mathematics and astronomy. For example, "Egyptian mathematics did not contribute positively to the development of mathematics." One of the major results, however, was a "deeper insight into the development of computation with fractions." The whole process was entirely additive. In the case of astronomy there is apparently only one very beneficial influence—namely, a calendar with a fixed time scale and no intercalations, which became the standard astronomical system of reference through the Middle Ages. "This calendar, indeed, is the only intelligent calendar which ever existed in human history." Incidentally, one "Egyptian contribution to astronomy is the twelve divisions of daytime and of night." Noteworthy by its omission in the text proper is any reference to the astronomical or mathematical significance of the Pyramids. The author con-

[1] "One of the tablets from Susa implies even a special problem of the eighth degree."

cludes this lecture with the interesting judgment that "Ancient science was the product of a very few men; and these few happened not to be Egyptians."

After this interlude we find ourselves searching for clues to ferret out the mysteries of Babylonian astronomy. Right at the start we are emphatically warned that "mathematical theory played the major role in Babylonian astronomy as compared with the very modest role of observations, whose legendary accuracy also appeared more and more to be a myth." The Babylonians, of course, were primarily interested in lunar, solar, and planetary phenomena close to the horizon. We are reminded that sandstorms frequently obscure the desert horizon so that "the almost proverbial brilliance of the Babylonian sky is more a literary cliché than an actual fact." Eclipses and occultations, on the other hand, are usually observable under more favorable conditions. Hence, "Ptolemy states that practically complete lists of eclipses are available since the reign of Nabonassar (747 B.C.), while he complains about the lack of reliable planetary observations. . . . Not a single text is known which could be called a wholly observational record. . . . We know so little about the underlying empirical material which was so skillfully applied to provide the basic parameters of a real mathematical theory." Incidentally, the zodiac (first mentioned in a Babylonian text of 419 B.C.) was invented to assist in the description of celestial motions. "Arithmetical progressions were skillfully utilized for the prediction of lunar phenomena with an accuracy of a few minutes." Babylonian astronomy was fully developed at about 300 B.C.

The last chapter, on the "Origin and Transmission of Hellenistic Sciences," is a natural climax for this challenging story. By this time we are conditioned to expect something like the following:

> If modern scholars had devoted as much attention to Galen or Ptolemy, they would have come to quite different results about the remarkable quality of the so-called Greek mind to develop scientific theories without resorting to experimental or empirical tests. . . . Plato's role has been widely exaggerated. . . . His advice to astronomers to replace observations by speculation would have destroyed one of the most important contributions of the Greeks to the exact sciences.

On the other hand, "the traditional stories of discoveries made by Thales or Pythagoras must be discarded as totally unhistorical."

Professor Neugebauer cites evidence for his conclusion that the mathematics of the Hellenistic period is part of an unbroken tradition from earliest ancient history to modern times. On the other hand, "The Elements of Euclid concern, with very few exceptions, a purely Greek development in a sharply defined direction." The axiomatic style of Eudoxios is to be sharply differentiated from that of Ionia and of southern Italy. Nor can credence be given to anyone claiming "repeated land measurements responsible for geometry;" it is "completely impossible to test any such hypothesis." In Hero's later degenerate geometry, indeed, one finds a reflection of the arithmetical or algebraic tradition of Mesopotamia.

The history of Greek astronomy presents a more involved problem than the history of mathematics, with its unique contribution over a relatively short period. For example, "there existed 'linear methods' of far wider extent than one could possibly have deduced from the silence of Ptolemy and his commentators." Furthermore, "essential parameters ascribed by Ptolemy to Hipparchus are identical with the corresponding parameters of the Babylonian theory." Hipparchus, indeed, used both geometric and arithmetic (linear) methods. The latter were particularly used also by astrological authors for horoscopes. Hence one finds "astrology . . . an exceedingly helpful tool for the transmission of Hellenistic thought." The Hindu and Babylonian contact, moreover, has been made primarily through the Greeks. Accordingly, "we stand today at the beginning of a systematic investigation of the relations between Hindu and Babylonian astronomy, an investigation which is bound to give us greatly deepened insight into the origin of both fields."

One of the small pleasures I personally derived from this stimulating book was the explanation of the arrangement of the Greek planetary week, which we still use today. It is "totally misleading when this order is called Chaldean in modern literature." Something new about something old! I strongly recommend this important summary to every scientist, particularly mathematical and physical scientists, and to every so-called humanist, particularly historians and philosophers. The excellent bibliography, notes, and references are instructive for mature specialists.

There are, of course, minor blots on this excellent record—for example, the spelling of Greek names. I felt somewhat unhappy, too, about the chronological table at the end. To be sure, "dates are only approximate." But why 1670 for Newton? What is the basis of the approximation? My major critical remark concerns the title itself. What are "the *exact* sciences in antiquity" or "the modern *exact* sciences" mentioned in the text? Are mathematics and astronomy to be regarded as a special single category of the sciences? As a physicist I would merely note the following predominant features: logic for mathematics, observations for astronomy, and experiments for physics. Webster's dictionary cites the phrase the "exact sciences" as an example of a usage of the word "exact" for denoting "capable of great nicety, especially in measurements." Perhaps this meaning might be applicable to some branches of physics, but not to most of astronomy, and certainly not at all to mathematics. In the last instance one might substitute an alternate dictionary meaning, namely, rigorous—a fighting word among modern mathematicians. I would personally prefer to give up this outmoded terminology.

RAYMOND J. SEEGER

National Science Foundation, Washington, D. C.