given us so enthralling a guide not only to the medicine but to the whole life of the ancient world. The illustrations in the second volume have been most skilfully chosen by Dr Miriam Drabkin and few of the seventy-five figures have been used before.

F. N. L. POYNTER

The Wellcome Medical Historical Library

## MEASUREMENT IN SCIENCE

*Quantification: A History of the Meaning of Measurement in the Natural and Social Sciences.* Edited by HARRY WOOLF (Bobbs-Merrill, Indianapolis, New York). Pp. 224.

This volume, like the well-known *Critical problems in the history of science* edited by Marshall Clagett, originated in a conference sponsored by the American Social Science Research and National Research Councils. Its aim was an "analysis of the introduction and development of the quantitative techniques in the natural and social sciences", with the presupposition, apparently, that this would prove a significant unifying topic for the sciences, and that lessons learnt in the more developed sciences might be applicable to those whose scientific status is more recent. The papers collected here are, with one exception, those presented at the conference, together with some afterthoughts added by the authors as a result of general discussion. The exception is the last paper, R. W. Gerard's "Quantification in biology", which was written after the conference, and treats quantification as a form of human behaviour, of interest to the neurophysiologist, rather than as an ingredient in the historical comparison of the sciences.

The main emphasis of the other articles is on the social sciences, and designedly so, for historians of science have so far paid much less attention to them than to the natural sciences. After a brief introductory paper by S. S. Wilks on some statistical aspects of quantification in the sciences, A. C. Crombie contributes an account of the partial mathematization of medieval physics, and discusses the intellectual and social reasons for the comparative absence of integration between theory and quantification. The dialogue between *episteme* and *techne* is for him one of the distinguishing marks of the seventeenth-century revolution. The next paper by T. S. Kuhn, "The function of measurement in modern physical science", is philosophically the most substantial of the symposium, and clearly provided leading themes for all the subsequent discussions. I shall return to it below. It is followed by H. Guerlac on quantification in chemistry, Richard Shryock on medical science, Edwin G. Boring on psychology, Joseph J. Spengler on economics, and Paul F. Lazarsfeld on "Trends, sources and problems" in the history of quantification in sociology—this

last a long but exceptionally rewarding paper, showing great insight into the historiographical problems of a comparatively new field.

Kuhn's paper begins with a challenge, and is an unashamed example of the use of history in the service of a philosophical thesis—"philosophy teaching by example". He sets out to show that our prevalent notions about the function and efficacy of measurement in physics are mythical. There is a textbook image of science in which numerical results are presented as if they correspond to and confirm numbers calculated from a theory, and this encourages the illusion that "the machine can be run backwards"—that laws and theories can be evolved out of measurements alone. But Kuhn argues that measurements never have this relation to theory. In the textbook they are mentioned only in order to *define reasonable agreement* between theory and experimental measurement, whereas in historical reality they normally have the function of mopping-up operations after a major theoretical breakthrough. Failure to obtain numerical agreement usually indicates failure to devise and design suitable experiments and to estimate reasonable approximation, rather than refutation of the theory. Only exceptionally do numerical anomalies create theoretical crises, and even then the function of measurement is more often to adjudicate between rival theories than to *confirm* any one of them. But all this, Kuhn adds in reply to criticisms in discussion, does not mean that *any* theory can be made to agree with experiments, or that qualitative experiments do not often suggest theories. It means rather that *measurement* as such is dependent upon previously agreed qualitative results, and upon a mature scientific community in which criteria of 'reasonable approximation' have been developed. The thesis is aptly illustrated from historical cases: Attwood's machine, Dalton's Law of Multiple Proportions, Coulomb's Law, and other examples of the mathematization of the 'Baconian sciences' (heat, light, electricity and magnetism) in the early nineteenth century.

The moral for science in general is, of course, reminiscent of Popper's account of scientific methodology, although to Popper's insistence on *testing*, Kuhn adds an historically-realistic emphasis on *exploitation* of theoretical ideas throughout their domain of application. Truly scientific measurements are never carried out at random or as straightforward confirmations of a theory, but because they are demanded in order to dot the i's and cross the t's of some incomplete theoretical conception. And quantification cannot be sought in order to enhance the prestige of a science, until in the fullness of time the proper qualitative foundations have been laid. If Kuhn is right in his interpretation, the consequences are important not only for the issues before this conference, but also for problems of the historiography of science in general. Some of the subsequent papers show signs of a desire to confine Kuhn's conclusions to the physical sciences, and indeed it is not immediately obvious that they

apply, for example, in economics and sociology, where experiment plays a smaller role than in physics. Even so, the same pattern emerges in several examples taken from the other sciences. Guerlac, for example, gives an account of quantification within the framework of prior qualitative distinctions of substances and elements which is perfectly compatible with Kuhn's conclusions, although Guerlac himself wants to insist on a theoretical and methodological hiatus between physical chemistry on the one hand, and traditional organic and inorganic chemistry on the other. There are further confirmations from the social sciences in subsequent papers, including some 'control' cases, such as those mentioned by Shryock, where apparent measurement at random (in seventeenth-century mechanistic physiology, and in attempts to quantify the patient's 'constitution') proved scientifically sterile.

But such a view as Kuhn's cannot in the end be proved or disproved by counting up historical cases, but only by the general coherence of the historical interpretations to which it gives rise. It is also connected with a basic epistemological thesis which, if valid at all, is valid for all the sciences. Since this is an historical work, however, it is more relevant to point out that the epistemological question is one on which the historian quickly betrays his own views. Here these views emerge only in asides. "Until the turn of the nineteenth century, the quantitative characteristics . . . we encounter in modern descriptions were almost totally lacking, chiefly but not solely because the facts were not available" (Guerlac, p. 67). But, Kuhn would say, facts do not lie about to be picked up, they have to be *fought for*. Or "The studies done in the 1600's . . .were largely non-quantitative, so that it was possible thereafter to elaborate the theory of a fire-substance (phlogiston) without any exact checks on it. This concept apparently impeded discovery of the nature of combustion for some seventy-five years" (Shryock, pp. 97–98). But here the problem was surely not just to "start measuring", but to find some theoretical framework which lent itself to quantitative exploitation better than the phlogiston theory. That theory was not irrevocably non-quantitative and inhibitory of measurement, as Priestley's persistent adherence to it demonstrates.

At worst, the myth that in a true science laws and theories somehow "rest on" measurement, may seriously distort the historian's selective emphasis. For a reviewer lamentably ignorant of the history of the social sciences it is impossible to tell whether this has happened in the subsequent papers in this volume. Many difficult and interlocking questions have to be sorted out here. There is first the basic question of whether Kuhn's thesis is epistemologically sound. There is also the question whether (as suggested by Shryock on p. 105, and by Boring on p. 115) the characters in the historical drama may *themselves* have entertained the false image of science which Kuhn describes, and if so, how far

it affected their science. And finally, there is the question of how far a certain epistemological blindness on the part of the historian can so confuse the trail that the answers to the first two questions can no longer be sought in the secondary sources alone. How easily relevant data might be overlooked is illustrated in Lazarsfeld's paper, where these epistemological questions are kept in full view. In 1693, he tells us, Halley published a paper on mortality based on figures for the city of Breslau, drawn to his attention by Leibniz. Who but Lazarsfeld would also tell us in a footnote that these figures were obtained *in order to refute a contention of the astrologers* that certain years in a man's life are especially dangerous (p. 150)?

These deeper questions relevant to an enquiry into quantification are unfortunately hardly touched on in the other papers, except in obvious response to Kuhn's provocation. It would therefore seem risky to draw any general conclusions from the chronicle-type histories presented there, individually interesting and informative though these are. Indeed a certain restiveness in this regard on the part of Professor Derek Price can be detected on p. 126! The moral for an investigation of this kind seems to be "Every historian a philosopher, and every philosopher his own historian".

MARY HESSE

University of Cambridge

## MATHEMATICS AT WORK

*Niccoló Tartaglia, Quesiti et Inventioni Diverse.* (Facsimile of the second edition of 1554.) Ed. A. Masotti (Ateneo di Brescia, 1959). LXXXV pages and 128 folios text.

The "mathematical practitioners" of the sixteenth and seventeenth centuries seem to be acquiring an important role in histories which deal with the origins of the Scientific Revolution. Now, it is the fashion to point beyond the great figures of the Golden Age to the lesser men who preceded them, and set the stage for later advance, by their success in educating the intellectual classes of Europe in the value of mathematics, as well as by their very failure to solve the chief problems their profession had set them. Those who are fascinated by questions of origins in the history of science and technology, find themselves driven more and more to investigate the sudden appearance, as it still seems, of this relatively large and active group. Among the first generation of these practitioners, few made a greater mark than Niccoló Tartaglia, whose works were translated into all the major European tongues, and whose influence in applied mathematics continued perceptibly for more than a century. It