played its part in creating the myth of the work's impenetrability, all too few of the methods there employed will individually—in divorce from the often highly ingenious manner of their dynamical application—seem novel to the student of our earlier volumes.

The final irony, of course, is that the *Principia* had its greatest influence only after being "translated" into algebraic terms by the rational mechanicians of the 18th century. The lectures on algebra and the development of the treatise on motion show Newton moving in the opposite direction. For all his references to algebra as a general or universal arithmetic, indeed as the science of "abstract relations of quantities" (volume 5, p. 132), he ultimately ranked geometry higher and sought to maintain its autonomy. Thus one finds in the lectures a full appreciation of the goals and techniques of algebra as they had emerged and been articulated by algebraists since François Viète, and yet, at the same time, a reaffirmation of the canons of Greek geometry. Toward the end, for example, Newton rejects Descartes's and others' classification of curves by the degree of their algebraic expressions in favor of the ancient criterion of simplicity of geometrical construction, even to the point of again separating the straight line and circle from the conic sections (though the revise in volume 5, pp. 538–621, does restore the algebraic ordering). Nonetheless, he goes on to show in great detail how various conic sections can be used to solve cubic problems also solvable by the geometrically simpler conchoid.

Indeed, the conic sections loom large in Newton's lectures on algebra. They are used to solve algebraic equations, and algebraic analysis in turn is used to construct the curves and determine their structural elements. Moreover, they play this major role in a treatise unusual for the number and variety of examples drawn from astronomy, optics, hydrostatics, statics, kinematics, and dynamics. That is, Newton's physical researches find their way into his algebraic lectures, thus linking the academic exercise with the magnum opus. But the link works against algebra. From the original treatise on motion to the last revisions of the *Principia*, some of the boldest mathematical innovations (and most signal failures; see Whiteside's remarks in volume 6, pp. 26–27) occur in the determination of planetary orbits, and it is fascinating to follow Newton's abandonment of the methods of Cartesian algebraic geometry in favor of what are now recognized as projective methods (see especially volume 6, p. 229ff). Whatever help Newton received from algebra and the method of fluxions and series, he saw the universe as a geometrical entity, and he preferred to treat it that way. How nicely the development of his thought in volume 6 tends to support Whiteside's observation in volume 5 (p. xii) that

> In later years, certainly, he grew increasingly soured with the often cumbersome computations and techniques of Cartesian algebra—at one point, indeed (if we may believe David Gregory), he qualified it as 'the Analysis of Bunglers in Mathematicks'—and we may be certain that his reluctance during 1705–6 to have Whiston edit the deposited text of his algebraic lectures was not merely the manifestation of a growing personal antagonism to his successor in the Lucasian chair.

Surely that reluctance had something to do with Newton's sense of the inadequacy of algebra in dealing with celestial mechanics.

All this is, of course, only a taste of the wealth to be found in the latest volumes of Newton's mathematical papers. On a more specific level, for example, one can follow Newton's attempts to construct a "Gravitational Theory of Optical Refraction" in which light corpuscles are constrained by a centripetal force to move on an orbit through a medium (volume 6, pp. 422–434), or his effort to establish a general theory of quadrature for algebraic curves (volume 6, pp. 450–455), or his painstaking but unsuccessful try at computing the rate of motion of the moon's apogee and mean secular advance (volume 6, pp. 508–537). Most important, one has a chance to tour Newton's mathematical mind accompanied by its surest modern guide. For lest the by now expected be overlooked, let us confirm Whiteside's continued mastery of historical editing and his encyclopedic knowledge of the work of Newton and his contemporaries. Is it niggling, however, to suggest that installments of the tour have become rather expensive for the private person?

MICHAEL S. MAHONEY
Program in History and Philosophy of Science, Princeton University

Laws That Govern Behavior

Psychophysics. Introduction to Its Perceptual, Neural, and Social Prospects. S. S. STEVENS. Geraldine Stevens, Ed. Wiley-Interscience, New York, 1975. vi, 330 pp., illus. $19.95.

In 1860, Gustav T. Fechner—physicist, physiologist, philosopher—published *Elemente der Psychophysik*. *Elemente* put forth a new science concerned with quantifying the relation between sensation and stimulus, and played a mighty role in the birth of experimental psychology. In 1975 appears *Psychophysics* by S. Smith Stevens—experimental psychologist and first professor of psychophysics (at Harvard). The new book sums up a scientific lifetime devoted largely to the problem posed by Fechner. Between these two books stands no work of comparable stature. Just as Fechner's volumes defined the field for the ensuing hundred years, so Stevens's publications, culminating in this book published two years after his death in January 1973, have since the late 1950's provided its leading paradigm.

Unlike *Elemente*, which followed ten years of intense experimentation but few publications, *Psychophysics* follows 40 years of both intensive research and numerous publications. *Psychophysics* weaves together many threads to provide a cohesive picture of the current and potential state of the art as Stevens saw it in 1972 when he finished the manuscript. His wife and editorial collaborator, Geraldine Stevens, put the finishing touches to the book.

Elemente, being all new, overflowed with theoretical and methodological details. *Psychophysics*, as a summation, could address major issues and leave most details to cited references. Whereas *Elemente* was a beginning *Psychophysics* is a culmination, but it is hardly a termination, for it boldly points the way to intriguing "prospects" in physiology and social psychology, prospects that have already begun to be realized. The major difference between *Elemente* and *Psychophysics* (aside from length and style) lies in the law that ties sensation magnitude, ψ, to stimulus magnitude, ϕ, and the way the law was formulated and justified.

Fechner wanted to measure sensation magnitude—how strong a stimulus appears—but he believed along with most of his contemporaries that measurement required units to add together. And how could a sensation be divided into pieces to be added together? As William James put it in his oft-quoted claim, "Our feeling of pink is surely not a portion of our feeling of scarlet; nor does the light of an electric arc seem to contain that of a tallow candle in itself." Fechner's solution was to assume that the smallest physical difference (jnd) that an observer can just notice between two magnitudes must evoke a constant subjective difference. Thus, in just barely distinguishing between two lines, say 50 and 50.5 centimeters long, we have, according to Fechner, the same subjective experience as in just distinguishing between 200 and 202 centimeters. Here seemed to be the needed unit of measurement. Given a constant *subjective* jnd and Weber's law, which says that the *stimulus* jnd increases in direct proportion to stimulus magnitude, Fechner's well-known logarithmic law followed: $\psi = k \log \phi$.

Having deduced his logarithmic law, Fechner concentrated much of the rest of his *Elemente* on procedures for measuring the jnd and the minimum, or absolute, threshold for detecting the presence of a stimulus. Psychophysics became largely identified with its methodology, and Fechner's law was the standard reference.

Stevens—from a great many experiments—*in*duced a different law, his power law, $\psi = a\phi^b$. Sensation magnitude is proportional to stimulus magnitude raised to an exponent. The size of the exponent varies from one sensory continuum to another—from loudness to sweetness to tactual vibration to coffee odor and so forth. The exponent may also be affected by stimulus conditions (for example, listening to a sound against an intense noise instead of in the quiet) or observer conditions (for example, judging brightness with the eyes light-adapted instead of dark-adapted). Unlike Fechner's logarithmic law, which made sensation magnitude always lag behind stimulus magnitude, Stevens's power law permits ψ to grow either more or less rapidly than ϕ. This flexibility was demanded by the data. Experiments showed that whereas some dimensions, such as loudness and brightness, grow more slowly than stimulus intensity, others, such as perceived duration and length, grow about as quickly as physical duration and length, and still others, such as sweetness, warmth, and electrical shock, grow more rapidly than their respective stimulus dimensions.

A good part of *Psychophysics* is about these data and how they were obtained. Stevens writes about how he originated and refined the appropriate methods, especially magnitude estimation. Observers estimate the magnitude of stimuli by assigning numbers to them. This procedure appears to meet the physicist N. R. Campbell's broad definition of measurement as the assignment of numbers to objects or events according to a rule. Magnitude estimation embodies the rule in the instructions to the observer. This approach freed psychophysics from the tyranny of the unmeasurable unit. But without a unit of measurement how could one determine the level of measurement achieved? In the late 1930's and early 1940's, Stevens developed his typology of scales of measurement according to which the achieved scale is defined by the ways in which the assigned numerals can be transformed—the more restricted the permissible transformations, the higher the scale of measurement. *Psychophysics* devotes a chapter to that development. In essence, rather than start with a unit of measurement as Fechner felt obliged to, Stevens first measured and then unitized.

Although Fechner, like Stevens, wanted to relate sensation magnitude to stimulus magnitude, his fixation on the unit put psychophysics into the business of measuring thresholds because the difference threshold or jnd yielded the purported unit and the absolute threshold provided the reference point. For nearly a hundred years, the chief exception to purely threshold measurements had to do with intramodal matches such as making two different hues equally bright or two different pitches equally loud, measurements for which Fechner's threshold procedures proved useful. *Psychophysics* shows how such intramodal matches can be derived from magnitude estimations and other direct scaling procedures and how, in turn, power functions are derivable from such matches. But these are not threshold measurements, and except for a chapter on the neural quantum (a steplike jnd), *Psychophysics* is exclusively about suprathreshold events, about sensations that are clear and vivid.

The formal difference between the threshold-based logarithmic law of 1860 and the power law of around 1960 implies several important facts about perception. The logarithmic law would mean that equal stimulus ratios yield equal sensation *differences*; the power law means that equal stimulus ratios yield equal sensation *ratios*. (Closely related is the rule that the *subjective* jnd increases in proportion to sensation magnitude.) Organisms perceive the world in terms of ratios, which are stable, not in terms of differences, which depend on ambient conditions. "When the sun goes behind a cloud and the light intensity falls by a large factor, the perceived relations among objects remain essentially as they were" (p. 226).

The power law does not go unchallenged. In reply, Stevens repeatedly cites "a multiple set of checks and counterbalancing investigations" (p. 293) which he sees as the scientist's sure means of settling controversies and solving paradoxes. Most impressive are the more than three dozen continua on which power functions have been demonstrated and the detailed parametric investigations of loudness, brightness, sweetness, tactual vibration, warmth, perceived weight, and the like.

To meet doubts about the validity of magnitude estimation, about the possibility that the assigned numbers tell us more about the observer's use of numbers than about his sensory experience, Stevens developed the cross-modality experiment. Instead of assigning numbers, the observer adjusts the strength of one stimulus until it seems as strong as a standard stimulus from a different sensory domain. For example, the observer may adjust a noise to sound as loud as a sucrose solution tastes sweet or make a light as bright as an odor smells strong. These cross-modality matches agree remarkably well with magnitude estimations; numbers are not needed although they do provide a convenient reference scale.

Another means of validating direct scaling procedures such as magnitude estimation may be via "objective" responses from single neurons, sensory nerves, and the cortex. Stevens's chapter on neural correlates gives many examples of data showing a power relation between one or another physiological response and stimulus magnitude. The physiological exponents are usually smaller than those measured behaviorally, but sometimes the two are surprisingly alike, as in the case of whole nerve potentials evoked by citric acid and sucrose in the chorda tympani of two human patients. The potentials and the patients' numerical estimates of taste intensity increased as the same power functions of stimulus concentration. While an impressive number of neural recordings support Stevens's power law, many do not. For that reason, Stevens saw the neural data as a beginning, hopeful but hardly decisive.

These neural measurements were important to Stevens not only because they could help validate the power law but because he believed that the critical boundary in sensation lies at the sensory transducer where stimulus energy is transformed into neural energy. He conjectured that "the power law tells us *what* the transducer does" (p. 208), that "the presence of power functions in the electrical recordings of neural events seems to affirm the hypothesis that the transducer imposes the power law in the sensory systems" (p. 224).

Stevens wrote clearly and succinctly, making telling points with a fine honed prose that seldom quibbled or waffled. Now, *Psychophysics* sums it all up beautifully, and also gives to the sensory psychologist and physiologist invaluable methodological and analytical hints and fascinating historical tidbits. At the same time, other psychologists, physicists, and scientists in general will find this clear, succinct introduction to a basic field full of wise advice about the scientific enterprise. Social scientists will find in the chapter on the scaling of the "social consensus" an interesting array of data derived from the application of Stevens's methods to the measurement of attitudes about crime, money, national power, social status, political dissatisfaction, and so forth.

Overriding all is Stevens's adventurous search for the invariant rules that he felt sure govern our behavior, in particular our sensory and perceptual behavior. The power law, repeatedly confirmed and vastly extended, satisfied that basic search. The power law answers the question Fechner posed back in 1860 about how sensation is quantitatively related to the stimulus. With a new paradigm established, science moves forward, refining, polishing, extending, so that psychophysics has already advanced too far for another single person to command the scope that Stevens still could in *Psychophysics*.

BERTRAM SCHARF
*Department of Psychology,
Northeastern University,
Boston, Massachusetts*

Modern Experiences

Becoming Modern. Individual Change in Six Developing Countries. ALEX INKELES and DAVID H. SMITH. Harvard University Press, Cambridge, Mass., 1974. xiv, 438 pp., illus. $15.

This is the kind of substantial research on a large subject that one always hopes to find but seldom does. If its implications are debatable—and they are—the debate will now be better informed.

Social and economic development has many consequences, among them being its effects on the way people think and feel about themselves and its effects on the standards by which people organize their lives. And on these subjects there are two schools of thought. According to the first, urbanization and industrialization are destructive of people as persons. They expose workers to a Hobbesian nightmare: to competition and exploitation. They assault them in body and in spirit, destroying their joy and their creativity, their humane tolerance for one another and their capacity for solidarity. They lower intellectual horizons and undermine feelings of personal worth. In the usual formulation, these consequences are thought more likely to occur if modern ways are introduced rapidly and under conditions of free-market capitalism.

Inkeles and Smith favor the second school of thought, and their expectations are quite different from the ones just described. From their reading of earlier research they conclude that the typical effects of economic development are an increase in personal freedom, confidence, and competence and a widening of horizons. In the research reported in this volume they have tried to measure each of a series of effects they expect; they conclude, on empirical and theoretical grounds, that the effects constitute a single dimension, Overall Modernity; and they employ a composite measure of that dimension as the dependent variable, using it in studies of approximately 1000 workers in each of six developing countries: Argentina, Chile, India, Israel, Nigeria, and East Pakistan (now Bangladesh).

It is worthwhile to itemize the expectations with which this research was begun. Inkeles and Smith think that more modern social conditions lead to more of the following characteristics in individuals: openness to new experience and to new ways of doing things; readiness for change (acceptance of changed opportunities, greater willingness to allow others to do things in new ways); being disposed to form and hold opinions on a large number of issues that arise within and outside one's immediate environment; being aware of the diversity of attitudes and opinions around one and valuing these variations in opinion; being informed about the wider world (knowing, for example, where Moscow and Washington are and that they are national capitals); being oriented to the present or the future rather than the past; believing that people can learn to exert considerable control over the environment, that they can better arrange human affairs, and that they can participate personally in this redesign of conditions affecting their own lives; feeling able to plan, valuing plans, and actually engaging in planning; seeing the physical and social worlds as calculable and dependable (believing, for instance, that the world is lawful, being willing to trust strangers); valuing technical skill and favoring a distribution of rewards to individuals according to the contributions they make through the exercise of skills; aspiring to educational and occupational advance for oneself and one's children (and valuing discoveries about the natural order as a source of solutions to human problems); awareness of, and respect for, the dignity of others (as, for example, in restraint in dealing with subordinates); understanding the logic of decisions at the basic level of production in industry.

One of the authors' achievements is the development of an interview in which all these points, and many others, are touched upon. This interview required six months of pretesting. Questions were worded so as to be understandable to persons of little or no education in six widely different cultures. The meaning of the questions was standardized across six languages. Safeguards were devised to prevent the results from being affected by the tendency of some respondents, especially of persons with little education, to "agree" with statements of opinion to which the interviewer wants a reaction. Systematic checks were made to ensure that respondents understood the meaning of the questions and that the interviewers did not substitute their own answers for those of the respondents. Because the interview was long (taking from three to four hours to conduct), the whole form was edited so as to provide an interesting and coherent experience for interviewees. Local people were recruited and trained to do all the interviewing and most of the supervising of the work in each country. It is a measure of the success of these efforts that almost all the people who fell within the authors' samples agreed to an interview, stayed with it to the end, and seemed to enjoy it.

There are many special samples in this study, but four provide the basic data. In each country, factories were selected from official lists. These factories were to come from at least three cities, one main industrial center and two lesser places. Half the factories were "traditional" and half "modern." (The modern factories were those that [i] treated their workers as citizens possessed of rights and as having a limited and clearly defined relation with the factory and [ii] had a management that showed much interest in the efficiency and continual improvement of factory organization and production [p. 176].) Two samples of workers were then chosen from each of these factories: a sample of men aged 18 to 32 who had worked in a factory for three or more years, and a sample of men, comparable with the first in age, education, ethnicity, and religion, who had had less than three months of factory experience. The third basic sample was matched as far as possible with the first and consisted of men working in agriculture who had had no industrial experience and who lived in the districts from which the industrial workers originated. The fourth basic sample, likewise designed to match the first, consisted of long-time urban workers who lacked both industrial experience and experience in other complex organizations.