BUCKINGHAM'S THERMODYNAMICS.

Theory of Thermodynamics. By EDGAR BUCKINGHAM, Ph.D. New York, The Macmillan Company, 1900. xi + 205 pp. Price, $1.90.

OLDFASHIONED, or, rather, elementary, thermodynamics deals mainly with the relations of heat and mechanical energy. It considers purely physical changes, including changes from any one to any other of the three states, solid, liquid and gaseous, but does not undertake to discuss chemical changes or such chemico-physical changes as occur in solution. Accordingly, from the purely mathematical point of view, elementary thermodynamics is shamefully simple. What possibilities of interest for the mathematician can be found in a beggarly array of only five variables, p, v, T, ϵ and η, subject to one characteristic equation and two general laws, so that only two of them at a time are capable of arbitrary variation? But from the standpoint of physical interpretation and application the study of thermodynamics, even in its elements, presents respectable difficulties, and is likely to be regarded by the beginner, however mathematical he may be, as something of a mystery.

On the other hand, when we undertake to deal with chemical changes, and find ourselves confronted by "i phases" of matter, each phase containing "a mixture of K substances," the variables, "normal" and "inverse," "internal" and "external," independent and dependent, begin to manœuver in regiments at the will of the commander, and the born mathematician finds himself in his proper element.

The book before us is intended for the help of those not very rare individuals who have some difficulty with both the physics of elementary thermodynamics and the mathematics of its broader generalizations. It is not for the beginner, although it deals with the very elements and discusses the two general laws at length. It is too circumspect, too precise, too thoroughgoing, in its examination for the student who is taking his first look at the field with which it has to do. It is rather for him who, after some months of growing acquaintance with the elementary facts and laws of thermodynamics, finds himself in doubt as to whether he fully understands, for example, the

nature of a reversible cycle or the theory of the "porous plug" experiments by means of which the "absolute thermodynamic scale of temperature" was brought to concrete existence. The very great care which the author uses in examining the premises of his science is shown by the following quotations. "It is usual to speak of this temperature [the temperature indicated by a thermometer in a mixture of liquids or gases] of the mixture as being also the temperature of the separate components, and this mode of expression does not lead us into any practical difficulties, although it has evidently no justification a priori" (page 2); "Our first idea of heat is that of something which increases the temperature of a body when added to it and decreases the temperature when taken away [a footnote here excludes melting, evaporation, etc., from immediate consideration]. The first addition which we make to this conception is the *assumption*, that *when a given body cools through a definite interval, the quantity of heat it gives out is always the same*, regardless of what becomes of the heat after it leaves the body in question" (page 9). Such care is admirable and in the main reassuring, even when it results in stamping as an assumption what most readers would be likely to take as an axiom. In at least one case, however, the author's caution seems to the reviewer too great; namely, on pages 9 and 10, where he raises the question, "Are two quantities of heat, which are equal to a third, equal to each other?" and disposes of it by the "definition," "that *quantities of heat which are equal to the same quantity are equal to one another.*" It is true that the author has been feeling his way to the conception that heat is "a quantity in the ordinary sense," but after he has got so far as to say that two quantities of heat are each equal to a third, it is too late for the need of any argument or definition to the effect that these two quantities are equal to each other.

The following definition, "Any process, of which the direction may be reversed by infinitely small modifications of the outside actions, is called a REVERSIBLE PROCESS," and, in general, everything that the author has to say about reversible or non-reversible processes is luminous, precise, and much to be commended.

In a word, even the reader who does not care for the chemical applications of thermodynamics, and who has no stomach for generalized coördinates, will find much in this book that he

can profit by, though it is not written for him alone or for him primarily.

But what of him whose ambition is to go further? For him there is an excellent brief chapter on The Conditions of Thermodynamic Equilibrium, and another on Thermodynamic Potentials and Free Energy. These are preceded by the necessary disquisition on the relations and functions of the indefinitely large number of variables which may be involved, and they are followed by a chapter of applications in which are discussed the electromotive force of a reversible galvanic cell, the equilibrium of phases of a single substance (triple point, etc.), and the phase rule of Gibbs. The discussion of the last subject disclaims the intention of being "either complete or rigorous"; but as an introduction "'tis enough, 'twill serve." There is, probably, no other book so well suited as this to the needs of him who is making preparation for an attempt to explore those tremendous abysses of thought, where reigns that condition of supernal calm known as the Equilibrium of Heterogeneous Substances.

But, alas! like the fellow who had never learned to read, and who found that no spectacles, however well contrived, would enable him to read, the reviewer gazes in vain through the medium of Dr. Buckingham's book at many a passage like the following in the famous third volume of the *Transactions of the Connecticut Academy*, "*the stability of any phase in regard to continuous changes depends upon the same conditions in regard to the second and higher differential coefficients of the density of energy regarded as a function of the density of entropy and the densities of the several components, which would make the density of energy a minimum, if the necessary conditions in regard to the first differential coefficients were fulfilled.*"

Through Nature to Gibbs should be the watchword of every devout thermodynamician, and if Dr. Buckingham has not succeeded in making the way easy, the failure is not his fault.

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CAMBRIDGE, MASS.,
July 23, 1902.