and fragmental volcanics, with occasional sediments interbedded. The Clarksburg formation is described by Dr. Bayley, who also, in Chapter V., discusses the various intrusive rocks that preceded the Clarksburg and those that follow it. In Chapter VI., H. L. Smyth describes in detail the interesting trough that runs off from the main Marquette syncline to the Republic mine. While the general relations are much like the large area, there are present of the Lower Marquette series only the Ajibik quartzite and the Negaunee iron-bearing formations, and of the Upper Marquette only the Goodrich quartzite and the Michigamme mica-schist. Minor peculiarities in local geology are also met. In Chapter VII., C. R. Van Hise gives a broad, general, structural discussion of the whole area. The monograph is illustrated by many plates and figures. The former include beautiful, colored reproductions of the rocks of the Negaunee formation that are associated with the iron-ores. An atlas of maps also accompanies the letterpress. Besides a general map there are thirty-five sheets of quarter townships, four inches to the mile.

The entire work is a monument to its authors and of incomparable interest alike to students of metamorphism, of economic geology and of structural geology. The mining operators of the region should find it a suggestive guide in new developments and exploratory work. The book is written in a clear and pleasing style which deserves commendation no less than does the scientific matter. J. F. KEMP.

The Phase Rule. By WILDER D. BANCROFT. Ithaca, N. Y., The Journal of Physical Chemistry. Large 8vo. Pp. viii+255. Paper. With numerous diagrams. Price, $3.00.

This interesting volume presents the subject of qualitative equilibrium of heterogeneous substances, on the basis of Gibbs' 'phase rule' and Le Chatelier's theorem. Mathematical theory, electro-chemistry and quantitative equilibrium are not discussed, but diverse phenomena in great variety, including the temperature, pressure and concentration of components are coördinated as examples of a few general principles. The general scope of the work can best be illustrated by a few subjects, selected from the many experimental data brought under review.

Water in an open vessel is not usually in a state of equilibrium, since evaporation takes place at the surface, and the liquid gradually diminishes in quantity. When the vapor is confined, in a limited space, its mass increases at any given temperature, until it exerts a certain definite pressure upon the surface of the water, and equilibrium results. With any change of temperature, some new pressure will be found before equilibrium is established; and if rectangular coördinates are used to represent the varying temperatures and pressures, some curved line will contain all the points which express conditions of equilibrium. Here is a system consisting of a single component in two phases, and the conditions of equilibrium are expressed graphically by a line. A definite change of either temperature or pressure or the density of water or vapor requires some definite change in another condition also. In this sense the conditions of equilibrium have but one degree of freedom, and the system is *monovariant.* Now, let the water be cooled until it begins to freeze. This implies a fixed temperature (0° C.) and a fixed vapor pressure of about 4.6 millimeters of mercury. If the system includes all three phases it is said to be *nonvariant*, and the conditions are represented by a single point in the diagram. At lower temperature the liquid will all freeze; at higher temperature the ice will melt. With increased pressure at zero all the vapor will be condensed; with diminished pressure all the liquid will gradually vaporize; in either case the system is reduced to two phases. A second curve of pressure can be drawn for ice in contact with vapor, and a third for ice in contact with liquid water, either system of two phases being *monovariant.*

When a salt, as potassium chloride, is added to the system in excess, there are two components, with the possibility of four phases; with the further addition of potassium nitrate, there are three components and may be five phases. In each case, if all components are present in the solid state, together with the saturated solution of all and the superincumbent vapor, the conditions of temperature, pressure and

concentration are all fixed; a change in any one of these conditions results in the elimination of one phase; or, if both temperature and pressure are made to change arbitrarily, equilibrium cannot be restored without the loss of two phases from the system. When two kinds of change may thus be made at pleasure, the system is said to be *divariant* and to have two degrees of freedom. It is here assumed that any disturbing effects due to gravity, electricity, capillarity or the distortion of solid masses are avoided, pressure and temperature being uniform throughout the system. The absolute and relative masses of the several phases have no effect upon equilibrium, except as some phase disappears entirely. The number of independent variables (including temperature and pressure) is two more than the number of components; and Gibbs' phase rule asserts that in the equilibrium of heterogeneous substances the number of degrees of freedom is equal to two more than the number of components, diminished by the number of phases. Thus, a non-saturated solution of a salt, in contact with vapor, may be altered at pleasure in regard to the concentration of the salt and either the temperature or the pressure; with two components in two phases, two arbitrary changes are subject to the will of the operator.

Le Chatelier's theorem asserts that "any change in the factors of equilibrium from outside is followed by a reverse change within the system." Thus, if a small amount of salt be added to the non-saturated solution, without change of temperature, this increase of concentration is offset in part by condensation of vapor and the pressure is therefore diminished. The system tends to return to its former condition of equilibrium by elimination of the disturbing element. Thus the sense of change resulting from the disturbance from conditions of equilibrium can be predicted, but the amount or rate of change involves quantitative relations which lie beyond the scope of the volume under review.

Experimental data are discussed, as indicated above, with regard to systems of one, two, three and four components. The relations of temperature, pressure and concentration are represented graphically. Much ingenuity has been shown in devising triangular diagrams to represent the relative masses of three substances by coördinates on a single plane. Melting and boiling points, critical temperature, allotropy, cryohydrates, solubility of anhydrous and hydrated salts, double salts, efflorescence, dissociation, supersaturation, volatile solutes, partially miscible liquids, eutectic mixtures and temperatures, fractional distillation, solid solutions, occlusion, alloys and fractional crystallization are among the subjects discussed, with numerous concrete examples.

The author's distinction between solvent and solute, or between solubility curve and fusion curve (as on pp. 36, 45, 95, etc.), does not find general acceptance. An attempt to determine the 'hypothetical line' of demarkation (page 158) may help to decide the point at issue.

While physical chemistry is rapidly gaining importance, many are deterred by the mathematical difficulties. To such, this work will give a welcome clew to the import of differential equations. Students of physical chemistry will here find a considerable field brought under review and duly systematized. Numerous indications are given of the present limitations of science and the open fields for profitable investigation.

ROBT. B. WARDER.

The Principles of Mathematical Chemistry; The Energetics of Chemical Phenomena. By DR. GEORG HELM. Authorized Translation by J. LIVINGSTONE R. MORGAN, PH. D. New York John Wiley & Sons; London, Chapman & Hall, Limited. 1897. 12mo. Pp. viii+228. Price, $1.50.

The original German edition has been recognized for three years or more as a work of value, and this translation will doubtless find a welcome. The principles of thermodynamics (including the conservation of energy) are asumed as the basis for the discussion. The intensity and quantity factors are distinguished in the various forms of energy, and the principle of constant or increasing entropy is applied to various reversible and non-reversible changes. Equations for chemical intensity are applied to electrolysis, simple chemical reactions, chemical equilibrium, freezing and boiling