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JOSIAH WILLARD GIBBS

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CHARLES S. HASTINGS

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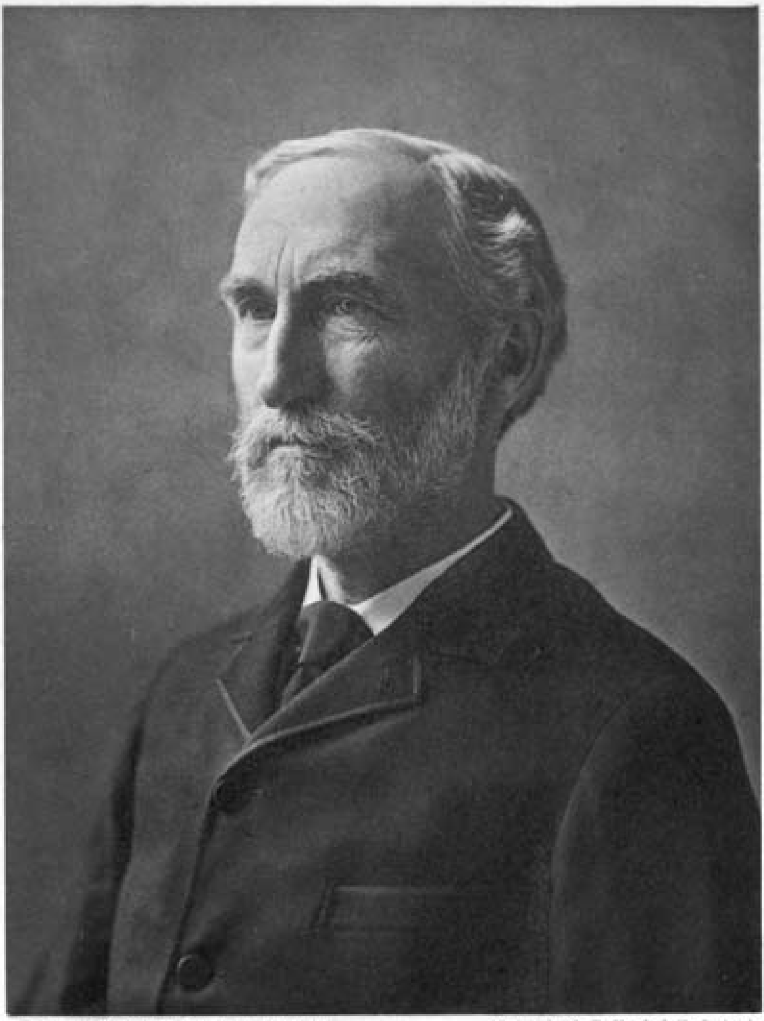

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J. Willard Gibbs

BIOGRAPHICAL MEMOIR OF JOSIAH WILLARD GIBBS.

JOSIAH WILLARD GIBBS was born in New Haven, February 11, 1839, and died in the same city on April 28, 1903; and New Haven remained his home during his whole life, for the only long absence from it was that of his period of study in France and in Germany which immediately followed his early experience as a teacher. Thus he was peculiarly identified with the intellectual life of New Haven and of Yale University, for no part of his education could have been regarded as uninfluenced by that ancient institution which, for the long period of thirty-seven years, counted his father a member of its faculty and which has always been dominant in shaping the methods of the Hopkins Grammar School, where his earlier studies were pursued. From this school he entered college in 1854, and received his bachelor's degree in 1858 with a record of distinction in Latin and in Mathematics. For five years after graduation he pursued studies in his chosen field, acquired the honor of a doctorate in 1863, and accepted an appointment as tutor in Yale College. That he taught Latin for two years and Natural Philosophy for the third and last of the years in which he retained this position should not lead one to think that his tastes at that time were unformed, nor that they were equally divided between two fields of thought so diverse. It is to be looked upon rather as a curious illustration of a former condition in our higher institutions of learning, when every distinguished graduate was supposed equally capable of teaching any subject pursued by undergraduates. At the end of the period of appointment he went to Europe for study, passing the winter of 1866-7 in Paris and the following year in Berlin. In 1868 he was in Heidelberg; and he returned to New Haven in 1869. Two years later he received an appointment to the professorship of Mathematical Physics in Yale College, a position which he retained until his death.

Professor Gibbs, during his first year in this newly established chair, had only two pupils, both now professors in Yale University and both members of the Academy. In the choice of work for this little class he was absolutely untrammeled either by precedent or by expressed preference of his pupils; hence the character of his teaching possesses a peculiar interest as an indication of the contemporary state of his scientific development which, perhaps, would be sought in vain elsewhere. The text of his choice was the Traité de Mécanique of Poisson, and the works most frequently quoted were those of Fresnel and of Cauchy. His lectures were for a considerable period confined to an exposition of the theories of Fresnel concerning diffraction, polarization, and the generalized laws of reflection; but this was followed by a remarkably interesting general treatment of waves, which, in successive chapters, was applied to a discussion of various types, such as water waves and those of light at the boundary in cases of total reflection. Long after this period one of his pupils extorted from him a conditional promise that he would publish this work on waves in book form, and it is much to be regretted that he never found a convenient time to do so; but there is little doubt that the insuperable difficulties in the mechanical explanation of double refraction forced themselves upon his mind at this time and turned his attention in a direction which led him later to his powerful support of the electro-magnetic theory of light. Certain it is that at this period of 1871-2 Professor Gibbs showed his chief interest in the domain of physical optics, and that his inspirations from without were derived from the French school of philosophers rather than from the German.

In the following year, 1872-3, Professor Gibbs chose a little work by Clausius, on the potential theory, as the basis of his lectures, a fact which is worth recording because it indicates that he had become acquainted with the writings of a physicist whose work he was shortly to extend in so remarkable a manner; for it was in April and May of 1873 that he presented before the Connecticut Academy the first of the papers on the mechanics of heat which have established his eminence for all time; and the immediate object of the paper, entitled "Graphical Methods in the Thermodynamics of Fluids," was to exhibit the fruitfulness of the conception of entropy, introduced by Clausius.

It is not a little singular that a man of such transcendent intellectual gifts, and one whose tastes for physical science were so pronounced, should have exhibited no desire to publish the results of his studies until he had attained such maturity; but from this epoch until his death, few years passed without his having contributed a paper of lasting importance either to physical science or mathematics. Perhaps the fact that the name of Professor Gibbs did not recur with greater frequency in current scientific literature caused some of his contemporaries to hold a false opinion of his fertility, but an inspection of his collected papers* would dispel every such impression. The exhaustive thoroughness with which every subject of his studies is there treated, as well as the absolute extent of his longer papers, imply vast and systematic industry.

The publication of these volumes brought forth many reviews and critical comments on the life and works of this eminent scholar from some of the leading physicists of the world;† but no one has been so advantageously situated or so successful in a general review of the aims and scope of these recondite papers as Professor Henry A. Bumstead. For years a follower of the later lectures of Professor Gibbs, he became afterward a colleague and a joint editor with Dr. Ralph Gibbs Van Name of the two volumes of collected papers; and it is not probable that any later writer on this subject will be able to add greatly to the extended and sympathetic review which prefaces the first volume of the Scientific Papers, nor would any admirer of the eminent scientist desire to see it curtailed. It reads as follows:

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*The Scientific Papers of J. Willard Gibbs. Longmans, Green & Co., London, New York, and Bombay; 2 volumes, 8°, 1906.

†Reference may be specifically made to the following:

Professor Joseph Larmor, London Times, Literary Supplement, March 22, 1907.

Professor C. S. Peirce, The Nation, January 7, 1907.

Professor J. H. Jeans, American Journal of Science, February, 1907.

An unnamed writer in the Bulletin des Sciences Mathématique; Aout, 1907.

Besides these appeared numerous shorter notices in the current journals of that year devoted to physics and to mathematics.

With this list might be mentioned the earlier memorial essay on Josiah Willard Gibbs, by Professor C. Alasia, in the Revista di Fisica, Mathematica, e Scienza Naturali; Pavia, 1905.

It was not until 1873, when he was thirty-four years old, that he gave to the world, by publication, evidence of his extraordinary powers as an investigator in mathematical physics. In that year two papers appeared in the Transactions of the Connecticut Academy, the first being entitled "Graphical Methods in the Thermodynamics of Fluids," and the second "A Method of Geometrical Representation of the Thermodynamic Properties of Substances by Means of Surfaces." These were followed in 1876 and 1878 by the two parts of the great paper "On the Equilibrium of Heterogeneous Substances," which is generally, and probably rightly, considered his most important contribution to physical science, and which is unquestionably among the greatest and most enduring monuments of the wonderful scientific activity of the nineteenth century. The first two papers of this series, although somewhat overshadowed by the third, are themselves very remarkable and valuable contributions to the theory of thermodynamics; they have proved useful and fertile in many direct ways and, in addition, it is difficult to see how, without them, the third could have been written. In logical development the three are very closely connected, and methods first brought forward in the earlier papers are used continually in the third.

Professor Gibbs was much inclined to the use of geometrical illustrations, which he employed as symbols and aids to the imagination, rather than the mechanical models which have served so many great investigators; such models are seldom in complete correspondence with the phenomena they represent, and Professor Gibbs's tendency toward rigorous logic was such that the discrepancies apparently destroyed for him the usefulness of the model. Accordingly he usually had recourse to the geometrical representation of his equations, and this method he used with great ease and power. With this inclination, it is probable that he made much use, in his study of thermodynamics, of the volume-pressure diagram, the only one which, up to that time, had been used extensively. To those who are acquainted with the completeness of his investigation of any subject which interested him, it is not surprising that his first published paper should have been a careful study of all the different diagrams which seemed to have any chance of being useful. Of the new diagrams which he first described in this paper, the simplest, in some respects, is that in which entropy and temperature are taken as coördinates; in this, as in the familiar volume-pressure diagram, the work or heat of any cycle is proportional to its area in any part of the plane; for many purposes it is far more perspicuous than the older diagram, and it has found most important practical applications in the study of the steam engine. The diagram, however, to which Professor

Gibbs gave most attention was the volume-entropy diagram, which presents many advantages when the properties of bodies are to be studied, rather than the work they do or the heat they give out. The chief reason for this superiority is that volume and entropy are both proportional to the quantity of substance, while pressure and temperature are not; the representation of coexistent states is thus especially clear, and for many purposes the gain in this direction more than counterbalances the loss due to the variability of the scale of work and heat. No diagram of constant scale can, for example, adequately represent the triple state where solid, liquid, and vapor are all present; nor, without confusion, can it represent the states of a substance which, like water, has a maximum density; in these and in many other cases the volume-entropy diagram is superior in distinctness and convenience.

In the second paper the consideration of graphical methods in thermodynamics was extended to diagrams in three dimensions. James Thomson had already made this extension to the volume-pressure diagram by erecting the temperature as the third coördinate, these three immediately cognizable quantities giving a surface whose interpretation is most simple from elementary considerations, but which, for several reasons, is far less convenient and fertile of results than one in which the coördinates are thermodynamic quantities less directly known. In fact, if the general relation between the volume, entropy and energy of any body is known, the relation between the volume, pressure, and temperature may be immediately deduced by differentiation; but the converse is not true, and thus a knowledge of the former relation gives more complete information of the properties of a substance than a knowledge of the latter. Accordingly Gibbs chooses as the three coördinates the volume, entropy, and energy, and, in a masterly manner, proceeds to develop the properties of the resulting surface, the geometrical conditions for equilibrium, the criteria for its stability or instability, the conditions for coexistent states and for the critical state; and he points out, in several examples, the great power of this method for the solution of thermodynamic problems. The exceptional importance and beauty of this work by a hitherto unknown writer was immediately recognized by Maxwell, who, in the last years of his life, spent considerable time in carefully constructing, with his own hands, a model of this surface, a cast of which, very shortly before his death, he sent to Professor Gibbs.

One property of this three dimensional diagram (analogous to that mentioned in the case of the plane volume-entropy diagram) proved to be of capital importance in the development of Gibbs's future work in thermodynamics; the volume, entropy, and energy of a mixture of portions of a substance in different states (whether in equilibrium or not) are the sums of the volumes, entropies, and energies of the separate parts, and, in the diagram, the mixture is represented by a single point which may be found from the separate points, representing the different portions, by a process like that of finding centers of gravity. In general this point is not in the surface representing the stable states of the substance, but within the solid bounded by this surface, and its distance from the surface, taken parallel to the axis of energy, represents the available energy of the mixture. This possibility of representing the properties of mixtures of different states of the same substance immediately suggested that mixtures of substances differing in chemical composition, as well as in physical state, might be treated in a similar manner; in a note at the end of the second paper the author clearly indicates the possibility of doing so, and there can be little doubt that this was the path by which he approached the task of investigating the conditions of chemical equilibrium, a task which he was destined to achieve in such a magnificent manner and with such advantage to physical science.

In the discussion of chemically homogeneous substances in the first two papers, frequent use had been made of the principle that such a substance will be in equilibrium if, when its energy is kept constant, its entropy cannot increase; at the head of the third paper the author puts the famous statement of Clausius: "Die Energie der Welt ist constant. Die Entropie der Welt strebt einem Maximum zu." He proceeds to show that the above condition for equilibrium, derived from the two laws of thermodynamics, is of universal application, carefully removing one restriction after another, the first to go being that the substance shall be chemically homogeneous. The important analytical step is taken of introducing, as variables in the fundamental differential equation, the masses of the constituents of the heterogeneous body; the differential coefficients of the energy with respect to these masses are shown to enter the conditions of equilibrium in a manner entirely analogous to the "intensities," pressure and temperature, and these coefficients are called potentials. Constant use is made of the analogies with the equations for homogeneous substances, and the analytical processes are like those which a geometer would use in extending to n-dimensions the geometry of three.

It is quite out of the question to give, in brief compass, anything approaching an adequate outline of this remarkable work. It is universally recognized that its publication was an event of the first importance in the history of chemistry, that in fact it founded a new department of chemical science which, in the words of M. Le Chatelier, is becoming comparable in importance with that created by Lavoisier. Nevertheless it was a number of years before its value was generally known; this delay was due largely to the fact that its mathematical form and rigorous deductive processes make it difficult reading for any one, and especially so for students of experimental chemistry, whom it most concerns; twenty-five years ago there was relatively only a small number of chemists who possessed sufficient mathematical knowledge to read easily even the simpler portions of the paper. Thus it came about that a number of natural laws of great importance which were, for the first time, clearly stated in this paper were subsequently, during its period of neglect, discovered by others, sometimes from theoretical considerations, but more often by experiment. At the present time, however, the great value of its methods and results are fully recognized by all students of physical chemistry. It was translated into German in 1891 by Professor Ostwald and into French in 1899 by Professor Le Chatelier; and, although so many years had passed since its original publication, in both cases the distinguished translators give, as their principal reason for undertaking the task, not the historical interest of the memoir, but the many important questions which it discusses and which have not even yet been worked out experimentally. Many of its theorems have already served as starting points or guides for experimental researches of fundamental consequence; others, such as that which goes under the name of the "Phase Rule," have served to classify and explain, in a simple and logical manner, experimental facts of much apparent complexity; while still others, such as the theories of catalysis, of solid solutions, and of the action of semi-permeable diaphragms and osmotic pressure, showed that many facts, which had previously seemed mysterious and scarcely capable of explanation, are in fact simple, direct, and necessary consequences of the fundamental laws of thermodynamics. In the discussion of mixtures in which some of the components are present only in very small quantity (of which the most interesting cases at present are dilute solutions) the theory is carried as far as is possible from *a priori* considerations; at the time the paper was written the lack of experimental facts did not permit the statement, in all its generality, of the celebrated law which was afterward discovered by van't Hoff; but the law is distinctly stated for solutions of gases as a direct consequence of Henry's law and, while the facts at the author's disposal did not permit a further extension, he remarks that there are many indications "that the law expressed by these equations has a very general application."

It is not surprising that a work containing results of such consequence should have excited the profoundest admiration among students of the physical sciences; but even more remarkable than the results, and perhaps of even greater service to science, are the methods by which they were attained; these do not depend upon special hypotheses as to the constitution of matter or any similar assumption, but the whole system rests directly upon the truth of certain experiential laws which possess a very high degree of probability. To have obtained the results embodied in these papers in any manner would have been a great achievement; that they were reached by a method of such logical austerity is a still greater cause for wonder and admiration. And it gives to the work a degree of certainty and an assurance of permanence, in form and matter, which is not often found in investigations so original in character.

In lecturing to students upon mathematical physics, especially in the theory of electricity and magnetism, Professor Gibbs felt, as so many other physicists in recent years have done, the desirability of a vector algebra by which the more or less complicated space relations, dealt with in many departments of physics, could be conveniently and perspicuously expressed; and this desire was especially active in him on account of his natural tendency toward elegance and conciseness of mathematical method. He did not, however, find in Hamilton's system of quaternions an instrument altogether suited to his needs, in this respect sharing the experience of other investigators who have, of late years, seemed more and more inclined, for practical purposes, to reject the quaternionic analysis, notwithstanding its beauty and logical completeness, in favor of a simpler and more direct treatment of the subject. For the use of his students, Professor Gibbs privately printed in 1881 and 1884 a very concise account of the vector analysis which he had developed, and this pamphlet was to some extent circulated among those especially interested in the subject. In the development of this system the author had been led to study deeply the *Ausdehnungslehre* of Grassmann, and the subject of multiple algebra in general; these investigations interested him greatly up to the time of his death, and he has often remarked that he had more pleasure in the study of multiple algebra than in any other of his intellectual activities. His rejection of quaternions, and his championship of Grassmann's claim to be considered the founder of modern algebra, led to some papers of a somewhat controversial character, most of which appeared in the columns of *Nature*. When the utility of his system as an instrument for physical research had been proved by twenty years' experience of himself and of his pupils, Professor Gibbs consented, though somewhat reluctantly, to its formal publication in much more extended form than in the original pamphlet. As he was at that time wholly occupied with another work, the task of preparing this treatise for publication was entrusted to one of his students, Dr. E. B. Wilson, whose very successful accomplishment of the work entitles him to the gratitude of all who are interested in the subject.

The reluctance of Professor Gibbs to publish his system of vector analysis certainly did not arise from any doubt in his own mind as to its utility, or the desirability of its being more widely employed; it seemed rather to be due to the feeling that it was not an original contribution to mathematics, but was rather an adaptation for special purposes of the work of others. Of many portions of the work this is of course necessarily true, and it is rather by the selection of methods and by systematization of the presentation that the author has served the cause of vector analysis. But in the treatment of the linear vector function and the theory of dyadics to which this leads, a distinct advance was made which was of consequence not only in the more restricted field of vector analysis, but also in the broader theory of multiple algebra in general.

Professor Gibbs was much interested in the application of vector analysis to some of the problems of astronomy, and gave examples of such application in a paper "On the Determination of Elliptic Orbits from Three Complete Observations" (Memoirs of the National Academy of Sciences, Vol. IV, Pt. 2, pp. 79-104). The methods developed in this paper were afterwards applied by Professors W. Beebe and A. W. Phillips* to the computation of the orbit of Swift's comet (1880 V) from three observations, which gave a very critical test of the method. They found that Gibbs's method possessed distinct advantages over those of Gauss and Oppolzer, the convergence of the successive approximations was more rapid, and the labor of preparing the fundamental equations for solution much less. These two papers were translated by Buchholz and incorporated in the second edition of Klinkerfues's *Theoretische Astronomie.*

Between the years 1882 and 1889, five papers appeared in the American Journal of Science upon certain points in the electromagnetic theory of light and its relations to the various elastic theories. These are remarkable for the entire absence of special hypotheses as to the connection between ether and matter, the only supposition made as to the constitution of matter being that it is fine-grained with reference to the wave-length of light, but not infinitely fine-grained, and that it does disturb in some manner the electrical fluxes in the ether. By methods whose sim-

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plicity and directness recall his thermodynamic investigations, the author shows in the first of these articles that, in the case of perfectly transparent media, the theory not only accounts for the dispersion of colors (including the "dispersion of the optic axes" in doubly refracting media), but also leads to Fresnel's laws of double refraction for any particular wave-length without neglect of the small quantities which determine the dispersion of colors. He proceeds in the second paper to show that circular and elliptical polarization are explained by taking into account quantities of a still higher order, and that these in turn do not disturb the explanation of any of the other known phenomena; and in the third paper he deduces, in a very rigorous manner, the general equations of monochromatic light in media of every degree of transparency, arriving at equations somewhat different from those of Maxwell in that they do not contain explicitly the dielectric constant and conductivity as measured electrically, thus avoiding certain difficulties (especially in regard to metallic reflection) which the theory as originally stated had encountered; and it is made clear that "a point of view more in accordance with what we know of the molecular constitution of bodies will give that part of the ordinary theory which is verified by experiment, without including that part which is in opposition to observed facts." Some experiments of Professor C. S. Hastings in 1888 (which showed that the double refraction in Iceland spar conformed to Huyghens's law to a degree of precision far exceeding that of any previous verification) again led Professor Gibbs to take up the subject of optical theories in a paper which shows, in a remarkably simple manner, from elementary considerations, that this result and also the general character of the facts of dispersion are in strict accord with the electrical theory, while no one of the elastic theories which had, at that time, been proposed could be reconciled with these experimental results. A few months later, upon the publication of Sir William Thomson's theory of an infinitely compressible ether, it became necessary to supplement the comparison by taking account of this theory also. It is not subject to the insuperable difficulties which beset the other elastic theories, since its equations and surface conditions for perfectly homogeneous and transparent media are identical in form with those of the electrical theory, and lead in an equally direct manner to Fresnel's construction for doubly-refracting media, and to the proper values for the intensities of the reflected and refracted light. But Gibbs shows that, in the case of a fine-grained medium, Thomson's theory does not lead to the known facts of dispersion without unnatural and forced hypotheses, and that in the case of metallic reflection it is subject to similar difficulties; while, on the other hand, "it may be said for the electrical theory that it is not obliged to invent hypotheses, but only to apply the laws furnished by the science of electricity, and that it is difficult to account for the coincidences between the electrical and optical properties of media unless we regard the motions of light as electrical." Of all the arguments (from theoretical grounds alone) for excluding all other theories of light except the electrical, these papers furnish the simplest, most philosophical, and most conclusive with which the present writer is acquainted; and it seems likely that the considerations advanced in them would have sufficed to firmly establish this theory even if the experimental discoveries of Hertz had not rendered such discussions forever unnecessary.

In his last work, "Elementary Principles in Statistical Mechanics," Professor Gibbs returned to a theme closely connected with the subjects of his earliest publications. In these he had been concerned with the development of the consequences of the laws of thermodynamics which are accepted as given by experience; in this empirical form of the science, heat and mechanical energy are regarded as two distinct entities, mutually convertible of course with certain limitations, but essentially different in many important ways. In accordance with the strong tendency toward unification of causes, there have been many attempts to bring these two things under the same category; to show, in fact, that heat is nothing more than the purely mechanical energy of the minute particles of which all sensible matter is supposed to be made up, and that the extra-dynamical laws of heat are consequences of the immense number of independent mechanical systems in any body—a number so great that, to human observation, only certain averages and most probable effects are perceptible. Yet in spite of dogmatic assertions, in many elementary books and popular expositions, that "heat is a mode of molecular motion," these attempts have not been entirely successful, and the failure has been signalized by Lord Kelvin as one of the clouds upon the history of science in the nineteenth century. Such investigations must deal with the mechanics of systems of an immense number of degrees of freedom and (since we are quite unable in our experiments to identify or follow individual particles), in order to compare the results of the dynamical reasoning with observation, the processes must be statistical in character. The difficulties of such processes have been pointed out more than once by Maxwell, who, in a passage which Professor Gibbs often quoted, says that serious errors have been made in such inquiries by men whose competency in other branches of mathematics was unquestioned.

On account, then, of the difficulties of the subject and of the profound importance of results which can be reached by no other known method, it is of the utmost consequence that the principles and processes of statistical mechanics should be put upon a firm and certain foundation. That this has now been accomplished there can be no doubt, and there will be little excuse in the future for a repetition of the errors of which Maxwell speaks; moreover, theorems have been discovered and processes devised which will render easier the task of every future student of this subject, as the work of Lagrange did in the case of ordinary mechanics.

The greater part of the book is taken up with this general development of the subject without special reference to the problems of rational thermodynamics. At the end of the twelfth chapter the author has in his hands a far more perfect weapon for attacking such problems than any previous investigator has possessed, and its triumphant use in the last three chapters shows that such purely mechanical systems as he has been considering will exhibit, to human perception, properties in all respects analogous to those which we actually meet with in thermodynamics. No one can understandingly read the thirteenth chapter without the keenest delight, as one after another of the familiar formulæ of thermodynamics appears almost spontaneously, as it seems, from the consideration of purely mechanical systems. But it is characteristic of the author that he should be more impressed with the limitations and imperfections of his work than with its successes; and he is careful to say (p. 166): "But it should be distinctly stated that, if the results obtained when the numbers of degrees of freedom are enormous coincide sensibly with the general laws of thermodynamics, however interesting and significant this coincidence may be, we are still far from having explained the phenomena of nature with respect to these laws. For, as compared with the case of nature, the systems which we have considered are of an ideal simplicity. Although our only assumption is that we are considering conservative systems of a finite number of degrees of freedom, it would seem that this is assuming far too much, so far as the bodies of nature are concerned. The phenomena of radiant heat, which certainly should not be neglected in any complete system of thermodynamics, and the electrical phenomena associated with the combination of atoms, seem to show that the hypothesis of a finite number of degrees of freedom is inadequate for the explanation of the properties of bodies." While this is undoubtedly true, it should also be remembered that, in no department of physics, have the phenomena of nature been explained with the completeness that is here indicated as desirable. In the theories of electricity, of light, even in mechanics itself, only certain phenomena are considered which really never occur alone. In the present state of knowledge, such partial explanations are the best that can be got, and, in addition, the problem of rational thermodynamics has, historically, always been regarded in this way. In a matter of such difficulty no positive statement should be made, but it is the firm belief of the present writer that the problem, as it has always been understood, has been successfully solved in this work; and if this belief is correct, one of the great deficiencies in the scientific record of the nineteenth century has been supplied in the first year of the twentieth.

In method and results, this part of the work is more general than any preceding treatment of the subject; it is in no sense a treatise on the kinetic theory of gases, and the results obtained are not the properties of any one form of matter, but the general equations of thermodynamics which belong to all forms alike. This corresponds to the generality of the hypotheses in which nothing is assumed as to the mechanical nature of the systems considered, except that they are mechanical and obey Lagrange's or Hamilton's equations. In this respect it may be considered to have done for thermodynamics what Maxwell's treatise did for electromagnetism, and we may say (as Poincaré has said of Maxwell) that Gibbs has not sought to give a mechanical explanation of heat, but has limited his task to demonstrating that such an explanation is possible. And this achievement forms a fitting culmination of his life's work.

Although the foregoing review demonstrates a vast amount of work, one must not conclude that it is an exhaustive catalogue of Professor Gibbs's activities. He is known to have made two interesting inventions in applied mechanics—one a brake for railway cars, which was patented,* and another, a type of governor of a higher order of approximation to astaticism than any of its predecessors, which was constructed in the machine shop of the Sheffield Scientific School and constitutes a valued apparatus in the collection of the Department of Physics. These incidents are quite sufficient to demonstrate that the inventor possessed all the mental qualifications necessary for a successful experimenter, and to render one curious as to why none of his published works includes any deductions founded upon experimental investigations of his own. Doubtless the reason is to be found in the fact that he was living in a period of intense activity in experimental research and record, so that he found abundant material already at hand to supply the quantitative data upon which he based his philosophical deductions. When this was wanting, however, no one in the circle of his intimates could doubt his capacity for supplying a deficiency by his own efforts. When

*U. S. Patent, No. 53971, April 17, 1866.

he was engaged upon his recondite analysis of the elastic theories of light he found what looked like a possible way of eluding the very great difficulties which come from the apparent non-existence of the compressural wave system; the tentative explanation, however, involved the occurrence of certain phenomena in specular reflection which had never been seen or, at least, recorded. As it did not seem to him that such negative evidence was conclusive, he constructed an apparatus with his own hands so perfectly adapted to the end in view that his observations afforded the proof sought. A striking light is thrown upon the character of the great physicist by the fact that no reference to this theory, which must have cost much critical study, appears in his writings, nor is it known that any one except the present writer ever saw the apparatus and made the experiment for which it was designed. Its only lasting effect was to add to the conviction, not at that time invincible, that the electromagnetic nature of light must be accepted as a verity.

As a member of the faculty of Yale University, Professor Gibbs constantly exhibited his interest in his work as an educator and manifested a reasonableness in his opinions no less striking than their occasional originality. With a perfectly courteous attitude toward those who differed from him, he never hesitated to express his views with extraordinarily clear logic and admirable diction. The severest criticisms of his colleagues were that his views were so broad, his opinions concerning important questions so carefully thought out and so judicial, that he often lacked the essential qualities of an advocate. His preferences in a proposed course of action were always obvious; but he could never blind himself to the advantages of a different course, and he seemed impelled to argue the affair as candidly with his associates as he did with himself. To one who knew his intellectual methods in pursuing a truth in the domain of physics, it was beautifully obvious that he did regard the administrative labors of a college faculty as a department of the exact sciences. When it became his duty to express an opinion on the merits of a candidate for higher academic honors, he was always kindly; he seemed as incapable of entertaining a very severe judgment of the intellectual deficiencies of a student as he was of holding his own achievements too highly. Fortunately, in his later life, at least, he had little to do with the inevitable disciplinary work of the college; but had he been called upon, we are sure that his tendency would always have been to err, if at all, upon the side of clemency.

It will surprise no reader of the numerous biographical notes concerning Professor Gibbs to learn that a man of so judicial a temperament was a very successful man of affairs. Happily for science, his position in the University was not such as to render that fact conspicuous, else he might have been called upon for work which, in view of his consciousness and inherent modesty, could easily have seriously interfered with his scientific pursuits. He did, however, give his services as a trustee to the affairs of the Hopkins Grammar School of New Haven, and he acted for many years as treasurer of its funds, which had come down in part from colonial times.

Nothing is more difficult in a biographical memoir than to give to the reader a definite impression of the personal characteristics of an eminent man, of those characteristics which make the man in the eyes of such of his contemporaries as are unable to estimate him by his works. On the other hand, there is no more legitimate curiosity than that which prompts us to seek such information about a man who has impressed himself upon his times by his essential greatness. In many cases a mere accumulation of incidents in the life of one who has numerous points of contact with his fellow-men is all that is necessary for a discerning reader; but with one whose activities are chiefly intellectual this is often difficult, and particularly so with Professor Gibbs, who seems never to have sought or desired a wide circle of acquaintances. But we should greatly err if we concluded from this that Mr. Gibbs was of an unsocial nature. To me he always appeared quite the opposite—perfectly friendly and approachable, ready to talk on any subject, and always equable, he exhibited a flattering welcome to every friend. Effusiveness was as foreign to his nature as insincerity, but cordiality was never wanting. He laughed readily and possessed a lively sense of humor. Though rarely speaking of himself, he occasionally borrowed an example or an illustration from his personal experiences. One may be recorded here, not only because of his enjoyment of its humor, but because his great papers on thermodynamics, which have brought him undying fame, were first published by the scientific society which received the curious criticism. A professor at the University of Berlin expressed to Mr. Gibbs, when he was there in 1868 attending various lecture courses, an interest in the Connecticut Academy of Arts and Sciences at New Haven. Mr. Gibbs gave the information demanded and casually stated that he himself was a member. This prompted the German scientist to the remark that "its memberships appear to be pretty freely bestowed." In the minds of students of recent history of science this story must awaken singular reflections, of which the humorous aspects would, perhaps, not be the most enduring. Still, although keenly alive to the pleasures of social intercourse, no one ever lived who was less dependent upon it. He seemed to have absolutely boundless resources within his own mind which would meet every want, whether for work or for pastime, and it was inevitable that such an exalted intellect should live much alone.

No qualities of Professor Gibbs impressed his sympathetic associates and his pupils more than his serenity and apparent unconsciousness of his intellectual eminence. Thoroughly characteristic and delightful is the remark which he once made to an intimate friend concerning his abilities as a mathematician. He said, with perfect simplicity and candor, "If I have had any success in mathematical physics, it is, I think, because I have been able to dodge mathematical difficulties."

Josiah Willard Gibbs was a member of a family which had long been distinguished for its scholars. He was descended from Robert Gibbs, the fourth son of Sir Henry Gibbs, of Honington, Warwickshire, who came to Boston about 1658. One of Robert Gibbs's grandsons, Henry Gibbs, in 1747 married Katherine, daughter of the Hon. Josiah Willard, secretary of the Province of Massachusetts. Of the descendants of this couple, in various parts of the country, no fewer than six have borne the name Josiah Willard Gibbs. On his father's side we find an unbroken line of six college graduates. Five of these were graduates of Harvard—President Samuel Willard, his son Josiah Willard, the great-grandfather, grandfather, and father of the elder Professor Gibbs, who was himself a graduate of Yale. Among his mother's ancestors were two more Yale graduates, one of whom, Rev. Jonathan Dickinson, was the first president of the College of New Jersey.

Many learned societies and universities have conferred their honors upon Professor Gibbs in recognition of his great services to science. The list of academies and societies of which he was a member includes the Connecticut Academy of Arts and Sciences, the National Academy of Sciences, the American Philosophical Society, the Dutch Society of Sciences, Haarlem; the Royal Society of Sciences, Göttingen; the Royal Institution of Great Britain, the Cambridge Philosophical Society, the London Mathematical Society, the Manchester Literary and Philosophical Society, the Royal Academy of Amsterdam, the Royal Society of London, the Royal Prussian Academy of Berlin, the French Institute, the Physical Society of London, and the Bavarian Academy of Sciences. He was the recipient of honorary degrees from Williams College, and from the universities of Erlangen, Princeton, and Christiania. In 1881 he received the Rumford Medal from the American Academy of Boston, and in 1901 the Copley Medal from the Royal Society of London

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