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JOSIAH WILLARD GIBBS AND THE EXTENSION OF THE PRINCIPLES OF THERMODYNAMICS

FIFTY years ago there was being published in the *Transactions* of the Connecticut Academy of Sciences a paper by Josiah Willard Gibbs, then professor of mathematical physics at Yale. This paper bore the title, "On the Equilibrium of Heterogeneous Substances." To-day from various parts of the world come notices and reports of meeting of societies and groups of scientific men engaged in apparently most diverse lines of investigation or industry, who, recognizing the lapse of fifty years and the changes they have brought, pause to recall the event of the publication of Gibbs's paper and to pay superlative tribute to the intellect and accomplishment of a man who influenced so profoundly the remarkable scientific progress made during this period.

It is therefore appropriate to call attention at this time to some of these memorial tributes and in particular to some of those expressed at the recent jubilee celebration held in his honor by the Chemical Society of Holland; for by quotations from them it may be realized through the words of eminent scientists the high esteem in which the most eminent American man of science is held throughout the world. By this means, too, something may be conveyed of his character, his industry, his wonderful ability for taking pains, and chiefest, his commendable lack of self interest in research.

It is worth while also to refer to the environment of Gibbs, since the environment of a man—especially the intellectual environment of an intellectual man—is an essential part of him and may largely determine the form and direction his intellectual activities shall take.

The period covered by the life of Gibbs, 1839–1903, was marked by an unusual interest and activity in physics. It is only necessary to recall the names of eminent physicists of that period to be assured of this. This interest, too, was general, and in so far as it pertained to the people at large, was inspired by the relation, then becoming more and more obvious, between the useful and practical applications of physics to industry and commerce. Industry was beginning to establish its laboratories and seek the leadership of scientific method.

The concept of energy was emerging during the early life of Gibbs and although not yet seen with enough precision to require a name and definition attempts had nevertheless already been made to define the possibilities of machines. In 1847 appeared the paper of von Helmholtz, "Die Erhaltung der Kraft," which needed only the substitution of the word *Energie* for that of *Kraft* to reveal in a most extended sense the principle of the conservation of energy that found so rational a place beside the principle of the conservation of mass that had earlier found expression.

The situation in physics during the formative years of Gibbs was not greatly unlike that that surrounds a young student at the present day. The attention is intensely directed to a new vision just ahead and its alluring possibilities. In the early years of Gibbs it was the concept of energy and the dynamical theory of heat, out of which ultimately grew the formulation of the first and second laws of thermodynamics and, in these still later days, the Theorem of Nernst. In the present day the vision is also alluring for it always pushes forward. It now seeks, though not an ultimate, yet a still more inclusive generalization through a better knowledge of the structure and mechanism of the atom. There is now scarcely any phase of physics uninfluenced by this new development—just as in Gibbs's youth the major interest was in statistical mechanics and thermodynamics.

Gibbs followed the trend of his time. He sought the inspiration and instruction of the pioneers who were establishing the laws and principles of the then new development in physics. The years 1867 to 1870 he spent as a student in Europe, studying there physics and mathematics, and, among other sources receiving inspiration from Magnus, Helmholtz, Kirchhoff and Clausius. These names are inseparably connected with the development of the principles of thermodynamics.

After his return from Europe, Gibbs was elected to the professorship of mathematical physics at Yale, 1871. The direction of his activities had now been determined even to subject and method. All his subsequent effort was to be directed to the mathematical analysis and investigation of thermodynamic problems. His methods were naturally influenced largely by those of Clausius and the problems he at first interested himself in referred to homogeneous systems. He employed the Carnot-Clausius cycle and the Clausius concept of entropy. In the prosecution of these earlier studies Gibbs made rapid progress. He greatly extended the graphic method of analysis. He invented the system energy, entropy, volume which proved of great value. This attracted the attention of Maxwell, whose last effort before his early death was to mould with his own hands a model developed from these three dimensions. This he sent to Gibbs. Gibbs is probably as well known through the graphic methods he introduced as by his more important theoretical contributions.

The problems possible of solution by the methods of Clausius and by those of Gibbs up till 1876 were confined almost exclusively to homogeneous systems. Besides, there entered into these analytical methods what further limited their practical applicability, *viz.*, the concept of reversibility. In reality most of the processes of nature and those most useful to men are irreversible and involve heterogeneous not homogeneous systems. To extend the principles of thermodynamics to include non-reversible and heterogeneous systems would be to make them universally applicable. This was an exalted vision; yet such a vision was the natural outcome of the progress that had already been made. Clausius had expressed this universality in the well-known couplet formulating the first and second law:

Die Energie der Welt ist konstant,
Die Entropie der Welt strebt einem Maximum zu.

This couplet—significant of the influence of Clausius, and recognizing no mechanism nor theory—Gibbs used as a text or sub-heading to his memorable paper "On the Equilibrium of Heterogeneous Substances."

The writings of Gibbs, however, show plainly that he early recognized the possibilities that might result from an extension of atomic and molecular theories and the use of statistical methods. But he realized also, at the time he was working, the meagerness of definite knowledge then existing for a more extended atomic theory. It will be noticed also from a quotation to be made that Ostwald was of opinion that the value of Gibbs's paper rests on the fact that he concerned himself exclusively with energy magnitudes and wisely avoided all kinetic hypotheses.

In the application to life and industry of fundamental principles of science that had already been formulated, the last fifty years have been the most active and productive in the world's history, even though they may not have been the most productive in the discovery of new ones. The result of the severe scrutiny and test of those years upon the work of Gibbs is perhaps nowhere better revealed than in the tributes publicly paid to his memory and accomplishments by those qualified to make use of and judge them.

That so important a piece of work should remain for fifteen years practically unknown after its publication in America is worthy of much contrite reflection—for the work itself is a model of what American thoroughness joined to vision can be, while its technical and public neglect over so long a period offers an equally notable example of what American haste and superficiality continue increasingly to be.

But some rumor of Gibbs's work finally did reach Europe; Öttingen mentioned it to Ostwald; Ostwald investigated—being particularly interested in the subject of chemical equilibrium. In his autobiography, "Lebenslinien," now being published, he recounts the incident quoted at the Holland celebration:

Öttingen had already mentioned to me while I was yet at Dorpat the existence of a work on thermodynamics by an American physicist. He had referred to it as significant, but difficult to follow.

In order to make myself clear concerning this mightiest of all means (thermodynamics) for developing a theory of chemical affinity, I began the study of Gibbs's paper after no little difficulty in trying to secure a copy of it. My experience with the paper tallied with that of Öttingen—I found it difficult to make headway in it, yet I recognized, and that without a doubt, its immense importance. Not many had anticipated me in the recognition of this work; previously, only Maxwell in England and van der Waals in Holland had referred to it.

There seemed no other way possible for me to gain an understanding of the work than to translate the paper word for word. An abstract of it was impossible because it was already so condensed that further abbreviation was out of the question. It was also my thought that by a German translation and publication of this long-neglected masterpiece it could be brought to light and allowed to take the place that its importance should merit among other investigations.

Gibbs's paper proved of the greatest influence on my own development, for—although he did not emphasize the point nor even mention it—Gibbs concerned himself exclusively with energy magnitudes and their factors and avoided completely all kinetic hypotheses. By so doing he won for his results a permanence and security that has placed them among the highest products of intellectual attainment. It is a fact that up to the present time, not a single error either in his formulae, his results, nor yet—and this is the most remarkable—in his assumptions has been found. Among scientific articles there are to be found not a few wherein the logic and mathematics are faultless, but which for all that are worthless because the assumptions and hypotheses upon which the faultless logic and mathematics rest do not correspond to actuality. In this most important respect the work of Gibbs is free from error.

This important work of the gifted American physicist was published by me (with his cooperation) in 1892 (fifteen years after its publication in America) under the title, "*Thermodynamische Studien.*" This was for a long time the only form in which this most significant contribution was available to the scientific world. . . . The German edition was soon exhausted and the book has long been out of print. It thus oddly came about that English and American students were obliged to study a work in German originally published but not available in the English language. Not until 1906 (thirty years after its first printing and three years after its author's death) Longmans brought out *in England* an edition of the few papers ever published by Gibbs. A German edition is now no longer necessary.

Willard Gibbs was an excessively modest and reserved genius. His entire life, with the exception of a few years spent elsewhere in study, was passed in New Haven, Connecticut, where his father before him was a professor in the university. Of his greatness—he is without question the greatest scientific genius the United States has produced—neither the citizens of his native town nor yet of America had any conception. He was to be discovered first in Europe. This occurred in Holland through the physicist van der Waals—in Germany through Öttingen and myself. In Holland an entire school of followers beginning with the student of Bemmelin, Bakhuis Roozeboom, has developed around a single one of the many generalizations that Willard Gibbs arrived at and published in his great work. The nucleus of the Holland group is the Phase Law of Gibbs. It was thus that by degrees the scientific world became aware that in Willard Gibbs dwelt a mind worthy to rank along side those of the great physicists Helmholtz, Clausius and W. Thompson.

The close consideration that I was compelled to give to the work of Gibbs in order to translate it was of great advantage to me. Although I was able to follow his mathematical processes only incompletely, I nevertheless acquired from the attempt to follow them an invaluable method of thought. I learned the value of the straightforward reality with which he grasped the separate problems and the exhaustive vision with which he marshaled his equations and developed from them far-lying consequences. Also I could not help but realize that the two hundred equations that his work embraced were, without exception, equations dealing with purely energy magnitudes. For me this fact had the greatest significance for it showed that *every fundamental Arbeit must be a work based upon the fundamental laws of energy.*"

Besides Ostwald, to whom the memory of Gibbs must owe a special debt of gratitude, many other Europeans participated in the jubilee celebration of the publication of Gibbs's work held by the Holland group.

Le Chatelier paid his respects to the memory of Gibbs upon this occasion. In his contribution he attributed to Gibbs the rôle of creator and designates his creation as the immense domain of *Méchanique Chimique*. He said:

This chapter of science Gibbs created and added to human knowledge where nothing had existed before; and this creation of his was so complete and perfect as it came from his hands that the fifty years that have passed have been able to add little or nothing to it. The numerous savants who have in the meantime concerned themselves with like questions have accomplished little more than a paraphrase of his work. They have perhaps completed some points in more detail; but more often they have only applied to particular cases laws formulated by Gibbs. Gibbs deduced and expressed his Phase Law in two pages; but there have been published many large volumes recording divers applications of it.

In 1899, twenty-two years after its American printing and five years after Ostwald's German translation appeared, Le Chatelier translated into the French language and published the paper of Gibbs.

An important tribute to the accomplishment of Gibbs was expressed by Professor Donnan, of London, whose notable work on membrane equilibria is one of the manifold applications of the principles formulated by Gibbs and here applied to thermodynamic investigations of life processes. It was Donnan's tribute to Gibbs on the occasion of the centenary celebration of the founding of Franklin Institute that came to many of our countrymen as a matter of news—came as a front page announcement of a great discovery—twenty years after the death of Gibbs. On that occasion he referred to the paper of Gibbs as "one of the mightiest works of genius the human mind has ever produced." In his contribution to the Holland jubilee, instead of dealing with his own special work and the relation it bore to the generalization of Gibbs, he dealt with the great unifying influence of the work of Gibbs as shown in the diversity of its application and in particular he dwelt on its immense practical value to industry. He said:

The systems with which the chemist is called upon to deal in the carrying out of industrial processes are usually of extreme complexity when viewed from the standpoint of kinetic and electronic theory. The exacting demands of modern life do not allow him to confine his labors to ideal solutions or ideal gas mixtures or to monatomic crystals in the neighborhood of absolute zero. The rapid advances of physics and physical chemistry in modern times undoubtedly hold out the hope that the time will come perhaps in no very distant future when the structure and activity of the material world will be understood in terms of a theory based on the potentialities and activities of electrons, protons and radiation, or possibly of radiant energy alone. Although such a theory already exists in outline, it is not sufficiently developed to suffice for the immediate needs of the chemist who is called upon to devise and control technical processes involving concentrated solutions of complex composition and often containing substances of complex molecular structure. During the past thirty or forty years, however, chemical science has been able to utilize, with immense benefit to itself, that part of physical science known as thermodynamics whereby the most complex equilibria can be dealt with quantitatively without any knowledge of the intimate "mechanisms" underlying physical and chemical phenomena. We owe the first complete and general exposition of the thermodynamics of multiple component systems, especially in relation to heterogeneous equilibria to the pioneer work of Josiah Willard Gibbs in the late seventies of the last century. . . . Donnan concludes his tribute by quoting from Sir William Pope the words, referring to Gibbs's Phase Law, "Who would have believed thirty years ago that the Phase Rule of Willard Gibbs would to-day be an important accessory to the manufacture of a number of heavy chemicals? Yet the men who learned the principles of this seemingly mathematical abstraction as students have revolutionized a great branch of chemical industry.

The address upon this occasion by Tammann, whose *Fach* is metallurgy and whose interests might seem remote from the physics of life processes that chiefly interest Donnan, contains this sentence:

Never has an abstract investigation so influenced the fundamental basis of industry as has the treatise of Gibbs on heterogeneous equilibrium.

Such quotations could be indefinitely extended. Those that have been given are not ephemeral; they are based by their authors upon a long and profitable personal experience leading to an ever-increasing knowledge and appreciation of the beauty, utility and value of the work of Gibbs. It has been mentioned that the universality of the principles of heterogeneous equilibrium was fully realized by Gibbs. The extent to which they have been realized in actuality is witnessed by the great number of investigations they have inspired and by their important results. These investigations cover the most diversified fields of human interest. A coordination of them in simple understandable terms would form one of the most interesting chapters in *Naturphilosophie.*

The hearty and sincere tributes of Europe to an American scholar might suggest one basis at least on which international amity is secure. But international amity even on so ideal a basis is not secure the moment the practical application of pure science is made by industry, and by the industry of that nation the best qualified to make application of it. Not only was the value of the work of Gibbs in the field of pure science first recognized by Europeans—the source from which the inspiration of Gibbs was wholly drawn—it was in Europe also that it found its most extensive and efficient application. The laws of heterogeneous equilibrium are the laws upon which are based industrial synthetic processes. Commerce has become familiar with many of its products.

When the possibilities and advantages of industrial appropriation of the results of pure science are in a degree realized from tangible results and the broad highway leading to them prepared and thrown open to all traffic, many interesting relations are revealed that are not directly recognized as those of pure physics. By way of suggestion, the following from Pasteur may be of interest:

> Science it is true is of no nationality . . . yet it is the highest personification of nationality. Science has no nationality because knowledge is the patrimony of all humanity—the torch that gives light to the world. Science should be the highest personification of nationality, because of all the nations that one will always be foremost that shall be first to progress by the labors of thought and intelligence.

F. W. STEVENS

WASHINGTON, D. C.

ARTHUR ARTON HAMERSCHLAG

ARTHUR ARTON HAMERSCHLAG, born in Nebraska, was a native of the West, educated in the East, honored for his work by university degrees and society fellowships. He was perhaps most widely known for his advancement of trade and technical educational methods, culminating in the presidency of the Carnegie Institute of Technology at Pittsburgh for a period of twenty years.

With the advent of the world war he gave his technical services to his country as advisory assistant to the Secretary of War. At its close he returned to technical engineering investigations as president of the Research Corporation of New York, a service closed by death on July 20, 1927, at the age of fifty-eight years.

Thus ended a life characterized by breadth of vision, tempered by scientific honesty, keen insight, careful judgment, deep concentration, the results of an analytical mind and ripe scholarship.

He made scientific studies of commercial problems which have added to industrial progress, and his advice was sought in many fields. His life was a busy one and many of his studies required a large outlay of time and patience to unravel. Yet, with all his duties and urgent demands on time, he was never too busy to give counsel and advice to young men. This phase of his activities is known to those directly affected, but not to the outside scientific and industrial world, where his technical attainments were so well recognized.

These young men were encouraged to do their best work, to seek advancement on merit. Their problems were discussed from all angles and solution reached, just as in his work for industrial companies. They reported to him at regular intervals on their work and progress. The advice was given in personal interviews and even more by correspondence, usually by return mail. The number of these men would run probably into the hundreds during his lifetime.

The results are shown in the high positions in the industrial world now held by these protégés of Dr. Hamerschlag. They serve as executives, superintendents, etc., in some of the largest industries. They owe to a very large extent their progress and acknowledge their success as due to this influence.

He appeared to take a special delight and pleasure in these reports and in the advancement of these men. He delighted in sketching their upward rise in business, though seldom giving the name of the man.

Scientific and technical attainments survive and become part of knowledge and science, but the personal influence of a great and helpful man becomes part of life and character. Character building is as important, if not more so, than scientific growth, but when both are combined, that man becomes notable.

In a world beset with complexities, worry, toil, the lightening of the load by encouragement and helpful advice to the discouraged is a real humanitarian service.

Dr. Hamerschlag was a great engineer and educator; he was also a most valuable adviser and spur to greater endeavor to many young men who will miss his help, but who have become better and more successful men by his life, and who are very glad to pay this tribute to his memory.

G. P. GRIMSLEY

BALTIMORE, MD.

SCIENTIFIC EVENTS

CENTENARIES OF 1927

IN the London *Times*, as quoted in *Nature*, Professor H. J. Spooner directs attention to some of the notable centenaries which occur this year. Among the names of men of science which he mentions are those of Newton, Laplace, Fresnel, Volta and Lister. The bi-centenary of the death of Newton will be celebrated at Grantham in March, while the centenary of the death of Volta is being recognized by the holding of an electrical exhibition at Como. The custom of commemorating such events should find general acceptance, for, as Fairbairn once remarked, "the smallest honor we can do the great benefactors of mankind is occasionally to bring them to our recollection." To the names mentioned others are added by *Nature*, which says: "Next in interest to mathematicians and astronomers, after Newton and Laplace, comes that of Robert Woodhouse (1773–1827), successively Lucasian professor and Plumian professor, to whom belongs the credit of introducing the calculus at Cambridge and who found earnest disciples in Babbage,