lication he carried the study of the relations between thermal energy and the energy of chemical reaction to a degree of completeness which rivals that of the older theory dealing with mechanical energy. It should be borne in mind that this older theory had to do with a far less complicated subject. As one of his biographers wrote:

> The older theory was the work of a number of men whose mathematical deductions were constantly being checked by experiment and who had the stimulus of mutual suggestions from each other's work. Professor Gibbs worked alone in a field in which he had no rivals and no helpers; he published practically all that he had to say upon the subject in a single paper of great length; and there were scarcely any experiments to which he could look for confirmation or suggestion as to his theoretical conclusions. Yet his very numerous results were correct, were of the highest importance, and were extremely general in application. Many things which had been mysteries, and concerning which our ignorance had been confessed by such vague terms as "affinity" or "catalytic action," were in this paper shown to be simple and direct consequences of the two laws of thermodynamics. Relations between facts and laws of chemical action were stated *a priori* which have since been verified by laborious and exact experiments; in fact there is little exaggeration, if any, in the statement that this paper contains, so far as general principles are concerned, practically the whole of the science which is now called physical chemistry and which had scarcely been begun when it was written. Considered merely as an intellectual *tour de force*, there are very few chapters in the history of science which can be compared with this; as an example of scientific prediction it is probably without a rival in the number and complexity of the relations discovered by *a priori* reasoning, in a science essentially experimental.

Notwithstanding the importance of this paper, it was a number of years before its value to the science of chemistry was fully appreciated. The cause of this delay was, in large measure, due to the fact that the author expressed his generalizations in terms of mathematics of which the average chemist of forty years ago was blissfully ignorant.

In 1892 the paper was translated into German by Ostwald and seven years later Le Chatelier translated it into French. In the preface to the German edition, the translator writes:

> The importance of the thermodynamic papers of Willard Gibbs can best be indicated by the fact that in them is contained, explicitly or implicitly, a large part of the discoveries which have since been made by various investigators in the domain of chemical and physical equilibrium and which have led to so notable a development in this field. . . . The contents of this work are to-day of immediate importance and by no means of merely historical value. For of the almost boundless wealth of results which it contains, or to which it points the way, only a small part has up to the present time been made fruitful. Untouched treasures of the greatest variety and of the greatest importance both to the theoretical and to the experimental investigator still lie within its pages.

Le Chatelier, in the foreword to the French edition, reminds his readers that

> To Professor Willard Gibbs belongs the honor of having created by the systematic use of thermodynamic methods a new branch of chemistry, the importance of which, daily increasing, has now become comparable to that of the gravimetric chemistry created by Lavoisier.

While it obviously lies beyond the scope of this paper to attempt an outline of this remarkable piece of work, it should be pointed out that many of its theorems have served as guides for experimental investigations of fundamental importance, while others have served to classify and explain, in a thoroughly satisfactory manner, the results of numerous researches. No one who is familiar with modern physical chemistry can study this paper without being profoundly impressed by the remarkable clearness with which Gibbs formulated many of its fundamental theorems, despite the fact that so little experimental data was available.

Thus, in his treatment of binary mixtures in which one of the components was assumed to be present in relatively small amount, he deduced the law of dilute solutions which, as is well known, was subsequently derived by Van't Hoff from the experimental data of Pfeffer and Traube.

One also finds a derivation of the exact relationship which obtains between the chemical energy transformed and the maximum electrical energy developed in a reversible galvanic cell. Gibbs clearly pointed out that the total thermal energy of the chemical reaction occurring within a galvanic cell is never completely transformed into electrical energy, unless the temperature coefficient of electromotive force is zero. This same relationship was independently discovered by Helmholtz about four years after the publication of Gibbs's paper; in consequence of this fact its mathematical formulation is commonly known as the "Gibbs-Helmholtz equation."

It was Gibbs who first pointed out, that at the surfaces of dispersed systems, a different concentration is to be expected from that which obtains in the body of the dispersoid. While he did not know or employ the modern concept of dispersed systems, his deductions were of such a general character that they may be applied to the special field of colloids.

Another generalization of interest to the chemist which was first clearly stated in this paper deals with the direction of change of vapor pressure which oc-