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Heidelberger Texte zur
Mathematikgeschichte

Gibbs, Josiah Willard

(11.2.1839 – 28.4.1903)

Materialsammlung
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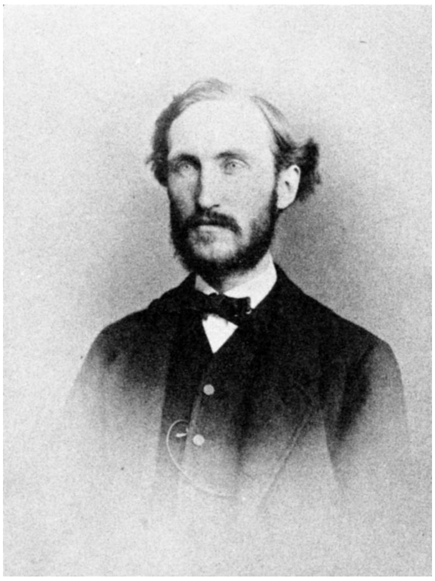
Josiah Willard Gibbs



Josiah Willard Gibbs 1867 in Berlin

Quelle:
Wheeler, Lynde P.: Josiah Willard Gibbs

Vom Sommersemester 1868 bis zum Frühjahr 1869 lebte der amerikanische Physiker Josiah W. Gibbs mit seiner Schwester Anna zu Studienzwecken in Heidelberg; er war aber nicht an der Universität immatrikuliert.
Evtl. hörte er im ▶ SS 1868[1] bei *Jakob Lüroth* "Theorie der algebraischen Formen" und wahrscheinlich im ▶ WS 1868/69[2] bei *Friedrich Eisenlohr* "Theoretische Optik"; denn J. Willard Gibbs schickte später an Jakob Lüroth Sonderdrucke aller seiner mathematischen Arbeiten aber an Eisenlohr nur seine Optik.

In dieser Zeit hatte Gibbs auch die Gelegenheit die schon berühmten Naturwissenschaftler Bunsen, Helmholtz und Kirchhoff zu hören. Außerdem besuchte er wahrscheinlich die Vorlesungen August Horstmanns „Physikalisch-theoretische Chemie" und „Thermodynamik mit Rücksicht auf die mechanische Wärmetheorie". Horstmann hat als erster den Entropiebegriff auf chemisches Gleichgewicht angewendet und erwähnt in einem Brief einen amerikanischen Zuhörer. (Hinweis von Prof. Herbert Wenzel, Erlangen)

[1] Link: http://digi.ub.uni-heidelberg.de/diglit/VV1865WSbis1870SS/0125
[2] Link: http://digi.ub.uni-heidelberg.de/diglit/VV1865WSbis1870SS/0145

Inhaltsverzeichnis

1 Lexika

Brockhaus — Die Enzyklopädie — 20. Aufl. — Leipzig
Bd. 8 (1996), S. 541

> **Gibbs,** Josiah Willard, amerikan. Mathematiker und Physiker, New Haven (Conn.) 11.2.1839, † ebd. 28.4.1903; wirkte seit 1871 als Prof. für mathemat. Physik am Yale College in New Haven. G. gehört zu den Begründern der modernen Thermodynamik (u.a. Einführung versch. thermodynamischer Funktionen und der für sie geltenden Gleichungen) sowie der statist. Mechanik. Weitere Untersuchungen galten der Theorie des chem. Gleichgewichts. Er schuf den Begriff der Phase und stellte 1876 die gibbssche Phasenregel auf. In der Mathematik lieferte G. Beiträge zur Theorie der Fourier-Reihen. Aus den hamiltonschen Quaternionentheorie und der graßmannschen Ausdehnungslehre entwickelte er die Vektoranalysis, die durch ihn Eingang in die theoret. Physik fand.
>
> **Werk:** Elementary principles in statistical mechanics ... (1902); dt. Elementare Grundlagen der statist. Mechanik ...).
> **Ausgaben:** The collected works, hg. v. W. R. LONGLEY u.a., 2 Bde. (Neuausg. 1957); The scientific papers, 2 Bde. (1906, Nachdr. 1993–94).
> L. P. WHEELER: J. W. G. The history of a great mind (Neuausg. New Haven,

Conn., 1962, Nachdr. Hamden, Conn., 1970); R. J. SEEGER: J. W. G. (Oxford 1974).

Mathematiker-Lexikon / Herbert Meschkowski

Studium an der Yale-Universität, in Paris, Berlin und Heidelberg. 1871 Professor für mathematische Physik in New Haven (USA).

Arbeiten auf dem Gebiet der Vektoranalysis und der Theorie der Fourierschen Reihen (≫Gibbssches Phänomen≪).

Lexikon bedeutender Mathematiker / hrsg. von Siegfried Gottwald ... — Thun [u.a.], 1990. — S. 171

Gibbs, *Josiah Willard:* geb. 11. 2. 1839 New Haven (Conn.), gest. 28. 4. 1903 New Haven; theoretischer Physiker. — G. promovierte 1863 am Yale College in New Haven, wo er Mathematik und Ingenieurwissenschaften studiert hatte. Maßgebend für seine weitere Laufbahn war vor allem eine dreijährige Studienreise durch Europa, wo er sich hauptsächlich in Mathematik und Physik weiterbildete. 1869 kehrte er nach New Haven zurück und wurde 1871 Prof. der mathematischen Physik am Yale College, wo er bis zu seinem Tode wirkte.

G. ist in erster Linie durch seine Beiträge zur Thermodynamik bekannt, beschäftigte sich aber auch mit der Optik, speziell mit der elektromagnetischen Theorie des Lichts von J. C. MAXWELL, und arbeitete die Grundlagen der statistischen Mechanik aus. Aus dieser Beschäftigung mit physikalischen Problemen gingen auch seine Beiträge zur Mathematik hervor. G.' Arbeiten, besonders sein Werk „Elements of Vector Analysis" (1881, 1884), bilden eine der Quellen für die moderne Vektoranalysis. G. hatte die bedeutendsten Traditionen der Mathematik und Physik seiner Zeit aufgegriffen und entsprechend den aktuellen Erfordernissen und dem wachsenden Interesse an der multilinearen Algebra durch Verarbeitung der Hamiltonschen Quaternionentheorie und der Graßmannschen Ausdehnungslehre ein neues System des Rechnens mit Vektoren geschaffen. Von O. HEAVISIDE war parallel und unabhängig ebenfalls aus dem Quaternionensystem ein dem *Gibbsschen Vektorsystem* äquivalentes entwickelt worden. Da aber G.' Darstellungen wegen ihrer gedrängten und knappen Form schwer verständlich waren und HEAVISIDE die Vektoranalysis mit dem sich ausdehnenden Gebiet der Elektrizität verband, ging deren weitere Verbreitung vor allem von den Arbeiten des letzteren aus. Neben zahlreichen Beiträgen zur Vektoranalysis kam G. vor allem das Verdienst zu, über seine neuen Ideen sofort Vorlesungen gehalten zu haben, wodurch er wesentlich zu ihrer Rezeption und Verbreitung beitrug. Außerdem bemühte er sich, den Vorteil der Anwendung der Vektoranalysis auf Probleme der Naturwissenschaften zu demonstrieren. 1899 schrieb er den Artikel über Vektoranalysis für die „Enzyklopädie der mathematischen Wissenschaften".

Poggendorff, Dictionary of Scientific Biography — Susann Hensel

Lit.: M. J. Crowe: A History of Vector Analysis. Notre Dame London 1967

2 Biographische Informationen

2.1 WWW-Biographien

- Josiah Wilard Gibbs[3] aus **MacTutor** history of Mathematics

  Josiah Willard Gibbs
  Born: 11 February 1839 in New Haven, Connecticut, USA
  Died: 28 April 1903 in New Haven, Connecticut, USA

  J Willard Gibbs' father, also called Josiah Willard Gibbs, was professor of sacred literature at Yale University. In fact the Gibbs family originated in Warwickshire, England and moved from there to Boston in 1658. However Gibbs is said to have taken after his mother in physical appearance.

  Gibbs was educated at the local Hopkins Grammar School where he was described as friendly but withdrawn. His total commitment to academic work together with rather delicate health m eant that he was little involved with the social life of the school. In 1854 he entered Yale College where he won prizes for excellence in Latin and Mathematics.

  Remaining at Yale, Gibbs began to undertake research in engineering, writing a thesis in which he used geometrical methods to study the design of gears. When he was awarded a doctorate from Yale in 1863 it was the first doctorate of engineering to be conferred in the United States. After this he served as a tutor at Yale for three years, teaching Latin for the first two years and then Natural Philosophy in the third year. He was not short of money however since his father had died in 1861 and, since his mother had also died, Gibbs and his two sisters inherited a fair amount of money.

  From 1866 to 1869 Gibbs studied in Europe. He went with his sisters and spent the winter of 1866–67 in Paris, followed by a year in Berlin and, finally spending 1868–69 in Heidelberg. In Heidelberg he was influenced by Kirchhoff and Helmholtz.

  Gibbs returned to Yale in June 1869 and, two years later in 1871, he was appointed professor of mathematical physics at Yale. [...] Rather surprisingly his appointment to the chair at Yale came before he had published any work. Perhaps it is also surprising that Gibbs did not publish his first work until 1873 when he was 34 years old. Few scientists who produce such innovative work as Gibbs did are 34 years of age before producing signs of their genius.

  Gibbs' important 1873 papers were *Graphical Methods in the Thermodynamics of Fluids* and *A Method of Geometrical Representation of the Thermodynamic Properties of Substances by Means of Surfaces.* In 1876 Gibbs published the first part of the work for which he is most famous *On the Equilibrium of Heterogeneous Substances*, publishing the second part of this work in 1878.

  The first of these papers describes diagrams in thermodynamics. [...] The second paper extended the diagrams into three dimensions and this work impressed Maxwell so much that he constructed a three dimensional model of Gibbs's thermodynamic surface and, shortly before his death, sent the model to Gibbs.

  However the third paper is the most remarkable. [...]

  Gibbs' work on vector analysis was also of major importance in pure mathematics. He first produced printed notes for the use of his own students in 1881 and 1884 and it was not until 1901 that a properly published version appeared

[3] Link: http://www-history.mcs.st-and.ac.uk/history/Mathematicians/Gibbs.html

prepared for publication by one of his students. Using ideas of Grassmann, Gibbs produced a system much more easily applied to physics than that of Hamilton.

He applied his vector methods to give a method of finding the orbit of a comet from three observations. The method was applied to find the orbit of Swift's comet of 1880 and involved less computation than Gauss's method.

A series of five papers by Gibbs on the electromagnetic theory of light were published between 1882 and 1889. His work on statistical mechanics was also important, providing a mathematical framework for quantum theory and for Maxwell's theories. In fact his last publication was *Elementary Principles in Statistical Mechanics* and this work is a beautiful account putting the foundations of statistical mechanics on a firm foundation.

Except for his early years and the three years in Europe, Gibbs spent his whole life living in the same house which his father had built only a short distance from the school Gibbs had attended, the College at which he had studied and the University where he worked the whole of his life. [. . .]

Article by: *J J O'Connor* and *E F Robertson*

February 1997

MacTutor History of Mathematics

[http://www-history.mcs.st-andrews.ac.uk/Biographies/Gibbs.html]

Auszug vom 4. Juni 2016

- Josiah Willard Gibbs[4] aus **Wikipedia**, der freien Enzyklopädie

  Josiah Willard Gibbs (* 11. Februar 1839 in New Haven, Connecticut; † 28. April 1903 ebenda) war ein US-amerikanischer Physiker.

  Gibbs studierte Mathematik und Naturwissenschaften an der Universität von New Haven. 1863 bis 1866 war er Tutor am Yale-College. Anschließend ging er nach Europa und setzte seine Studien in Paris, Berlin und Heidelberg fort. 1871 wurde Gibbs zum Professor an der Yale-Universität in New Haven ernannt.

  Zwischen 1876 und 1878 schrieb er eine Artikelserie mit dem Gesamttitel *On the Equilibrium of Heterogeneous Substances*, die als eine der größten Errungenschaften in der Physik des 19. Jahrhunderts angesehen wird und als Grundlage der physikalischen Chemie gilt. In diesen Artikeln wandte Gibbs die Thermodynamik an, um physikochemische Erscheinungen zu interpretieren. Zu den erörterten Lehrsätzen gehört auch die Gibbssche Phasenregel. Gibbs' Artikel über Thermodynamik erschienen in den *Transactions of the Connecticut Academy. On the Equilibrium of Heterogeneous Substances* wurde 1891 ins Deutsche und 1899 ins Französische übersetzt; die enthaltenen Lehrsätze wurden in Europa bekannt und angewandt. Besondere Verbreitung erfuhren sie dabei durch die experimentellen Arbeiten von H.W. Bakhuis Roozeboom. 1880 wurde er zum Mitglied in die American Academy of Arts and Sciences in Cambridge, Massachusetts gewählt. Ab 1897 war er auswärtiges Mitglied der Royal Society.

  Gibbs erbrachte auch hervorragende Leistungen für die statistische Mechanik, die Vektoranalysis und die elektromagnetische Theorie des Lichtes. Seine *Scientific Papers* (1906) und *Collected Works* (1928) wurden gesammelt und nach seinem Tod veröffentlicht.

  Für die Vektoranalysis schuf Gibbs eine Methode, die mathematische Entwicklungen wesentlich vereinfachte, die seinerzeit die theoretische Behandlung der Maxwellschen Elektrodynamik stark voranbrachte.

[4]Link: http://de.wikipedia.org/wiki/Josiah_Willard_Gibbs

> Er definierte ebenso die Gibbs-Energie $G = U + pV - TS$ bei konstanter Temperatur und konstantem Druck, die auch als Freie Enthalpie bekannt ist.
>
> Auch das Gibbssche Phänomen, das Gibbssche Paradoxon, die Gibbs-Duhem-Gleichung, und die Gibbs-Helmholtz-Gleichung sind nach ihm benannt. Er führte den Ensemble-Begriff in die Statistische Mechanik ein, wo heute das Kanonische Ensemble auch Gibbs-Ensemble heißt.
>
> Die Willard Gibbs Medal der American Chemical Society trägt seinen Namen und die Gibbs Lecture der American Mathematical Society. Außerdem sind der Mondkrater Gibbs und der Asteroid (2937) Gibbs nach ihm benannt.
>
> Auszug vom 4. Juni 2016

- Wikipedia englisch[5]

- American Institute of Physics[6]
- University of Houston[7]
- Chemistry explained[8] / Michael J. Fosmire
- Corrosion Doctors[9]
- Columbia Electronic Encyclopedia[10]
- [PDF] Biographical memoir of Josiah Willard Gibbs[11] by Charles S. Hastings (National Academy of Sciences, Washington, 1909)

2.2 Print-Biographien

Dictionary of Scientific Biography. — New York
Vol. 5 (1972), p. 386–383
Signatur UB Heidelberg: LSN B-AE 014

> He spent a year each at the universities of Paris, Berlin, and Heidelberg, attending lectures in mathematics and physics and reading widely in both fields.

Bulletin of the American Mathematical Society
Vol. NS 9 (1902/03), p. 517
Signatur UB Heidelberg: L 21-1-4::2: 9.1902-03

> *Professor Josiah Willard Gibbs,* of Yale University, dies at New Haven, April 28, 1903, of heart disease. He was born in New Haven, February 11, 1839, and graduated at Yale in 1858. After receiving the doctor's degree in 1863 from the same institution, he studied in Paris, Berlin, and Heidelberg. In 1871 he was appointed to the professorship of mathematical physics at Yale which he held to the time of his death. Professor Gibbs was a member of the Royal Society of London, of the National Academy of Sciences, and

[5] Link: http://en.wikipedia.org/wiki/Josiah_Willard_Gibbs
[6] Link: http://www.aip.org/history/exhibits/gap/Gibbs/Gibbs.html
[7] Link: http://www.uh.edu/engines/epi119.htm
[8] Link: http://www.chemistryexplained.com/Ge-Hy/Gibbs-Josiah-Willard.html
[9] Link: http://www.corrosion-doctors.org/Biographies/GibbsBio.htm
[10] Link: http://www.infoplease.com/ce6/people/A0820757.html
[11] Link: http://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/gibbs-josiah.pdf

of many other learned bodies. Quite recently he joined the *American Mathematical Society.* He was an authority of the first rank in thermodynamics and in the application of vector analysis to physical problems.

Bumstead, Henry A.:
Josiah Willard Gibbs
Mit Bibliographie
In: *American journal of science. — 166 (1903),* S. 186–202
Signatur UB Heidelberg: O 4030::166.1903
Erweiterte Version mit Fotografie: ▶ Anhang A In: *The collected Works of J. Willard Gibbs.* — reprint. — Bd. 1 (1948), S. XIII–XXVIII
Signatur UB Heidelberg: O 4218-0-5::1

Josiah Willard Gibbs
In: *Proceedings of the London Mathematical Society. — 1 (1904),* S. 19–21
Signatur UB Heidelberg: L 16-1::2: 1.1904

Langer, R. E.:
Josiah Willard Gibbs
In: *American mathematical monthly. — 46 (1939),* S. 75–84
Math.Bibl.

Wheeler, Lynde P.:
Josiah Willard Gibbs : the history of a great mind. — New Haven, Conn., 1951
▶ Anhang B
Signatur UB Heidelberg: F 6773-25
In den Adresslisten Gibbs' (S. 237) ist Prof. J. *Lüroth* in Freiburg, Baden für alle mathematischen Arbeiten benannt; dagegen Frederich [sic!] *Eisenlohr* in Heidelberg nur für die Optik.

3 Werk

In Heidelberg vorhandene **Monographien Josiah W. Gibbs**

- The collected works
  1. 1948
     Signatur UB Heidelberg: O 4218-0-5::1.1948
  2. 1948
     Signatur UB Heidelberg: O 4218-0-5::2.1948
- Elementary Principles in statistical Mechanics developed with especial reference to the rational Foundation of Thermodynamics
  - New York, 1902
    Signatur UB Heidelberg: O 5262-12-5
  - Elementare Grundlagen der statistischen Mechanik. - Leipzig, 1905
    Signatur UB Heidelberg: O 5262-12-6
- On multiple algebra. - Salem <Mass.>, 1886
  Signatur UB Heidelberg: Za 3432,2
- Thermodynamische Studien. - Leipzig, 1892
  Signatur UB Heidelberg: O 5262

- (Wilson, Edwin Bidwell:) Vector analysis founded upon the lectures of J. Willard Gibbs. - New York ; London, 1902
  Signatur UB Heidelberg: L 1277

3.1 Mathematische Arbeiten J. Willard Gibbs'

- Elements of vector analysis. — New Haven, 1881 and 1884
- On multiple algebra
  In: *Proceedings of the Amercian Association for the Advancement of Science. — 33 (1886),* S. 37–66
- On the role of quaternions in the algebra of vectors
  In: *Nature. — 43 (1891),* S. 511–514
- Quaternions and the Ausdehnungslehre
  In: *Nature. — 44 (1891),* S. 79–82
- Quaternions and vector analysis
  In: *Nature. — 48.1893,* S. 364–367

3.2 J. Willard Gibbs über eigene Schriften

On the Equilibrium of Heterogenous Substances[12]
Eigenreferat der in Band III (1876/78) der *Transactions of the Connecticut Academy of Arts and Sciences* erschienenen Publikation in der Referatezeitschrift *Repertorium der literarischen Arbeiten aus dem Gebiete der reinen und angewandten Mathematik.* — Bd. 2 (1879), S. 300–320

3.3 Literatur über das Werk J. Willard Gibbs'

Donnan, Frederick G. [Hrsg.]
A Commentary on the Scientific Writing of J. Willard Gibbs. — 1936
UB:O 4218-0-6

Smith, Percey F.:
Josiah Willard Gibbs : a short sketch and appreciation of his work in pure mathematics
In: *Bulletin of the American Mathematical Society. — 10 (1903)*
Signatur UB Heidelberg: L 21-1-4::2: 10.1903-04

4 Bibliographien

Biographisch-literarisches Handwörterbuch / J. C. Poggendorff. — Leipzig
Bd. 3 (1898), S. 513–514
Bd. 4 (1904), S. 496
Bd. 5 (1925), S. 424
Bd. 6,2 (1937), S. 884
Signatur UB Heidelberg: LSN B-AE 002 und LSA Nat-A 001

[12] Link: http://www.ub.uni-heidelberg.de/archiv/13220

Bibliographie (S. 201–202) aus
Bumstead, Henry A.: Josiah Willard Gibbs ▶ Anhang A (S. 21–23)
In: *American journal of science.* — 166 (1903), S. 186–202
Signatur UB Heidelberg: O 4030::166.1903

Anfrage an Zentralblatt Math zum Autor *Gibbs, J** oder zum Titel *J* Willard Gibbs.*
Die auf *Gibbs, J** standardmäßig reduzierte Autorenanfrage liefert noch die Werke anderer Autoren. Für ein korrektes Ergebnis ist die Autoren-Suche auf *Gibbs, J* Willard* zu ändern.

Anhang

A Henry A. Bumstead: Josiah Willard Gibbs

[Reprinted with some additions from the *American Journal of Science*, ser. 4, vol. xvi., September, 1903.]

JOSIAH WILLARD GIBBS was born in New Haven, Connecticut, February 11, 1839, and died in the same city, April 28, 1903. 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, and of the descendants of this couple, in various parts of the country, no fewer than six have borne the name Josiah Willard Gibbs.

The subject of this memorial was the fourth child and only son of Josiah Willard Gibbs, Professor of Sacred Literature in the Yale Divinity School from 1824 to 1861, and of his wife, Mary Anna, daughter of Dr. John Van Cleve of Princeton, N.J. The elder Professor Gibbs was remarkable among his contemporaries for profound scholarship, for unusual modesty, and for the conscientious and painstaking accuracy which characterized all of his published work. The following brief extracts from a discourse commemorative of his life, by Professor George P. Fisher, can hardly fail to be of interest to those who are familiar with the work of his distinguished son: "One who should look simply at the writings of Mr. Gibbs, where we meet only with naked, laboriously classified, skeleton-like statements of scientific truth, might judge him to be devoid of zeal even in his favorite pursuit. But there was a deep fountain of feeling that did not appear in these curiously elaborated essays. ... Of the science of comparative grammar, as I am informed by those most competent to judge, he is to be considered in relation to the scholars of this country as the leader." Again, in speaking of his unfinished translation of Gesenius's *Hebrew Lexicon*: "But with his wonted thoroughness, he could not leave a word until he had made the article upon it perfect, sifting what the author had written by independent investigations of his own."

The ancestry of the son presents other points of interest. 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.

Josiah Willard Gibbs, the younger, entered Yale College in 1854 and was graduated in 1858, receiving during his college course several prizes for excellence in Latin and Mathematics; during the next five years he continued his studies in New Haven, and in 1863 received the degree of doctor of philosophy and was appointed a tutor in the college for a term of three years. During the first two years of his tutorship he taught Latin and in the third year Natural Philosophy, in both of which subjects he had gained marked distinction as an undergraduate. At the end of his term as tutor he went abroad with his sisters, spending the winter of 1866–67 in Paris and the following year in Berlin, where he heard the lectures of Magnus and other teachers of physics and of mathematics. In 1868 he went to Heidelberg, where Kirchhoff and Helmholtz were then stationed, returning to New Haven in June, 1869. Two years later he was appointed Professor of Mathematical Physics in Yale College, a position which he held until the time of his death.

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 coordinates; 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 counter-balances 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 coordinate, 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 coordinates 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 coordinates 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.

The theory of dyadics[1] as developed in the vector analysis of 1884 must be regarded as

[1]The three succeeding paragraphs are by Professor Peroey F. Smith ; they form part of a sketch of Professor Gibbs's work in pure mathematics, which Professor Smith contributed to the Bulletin of the American Mathematical Society, vol. x, p. 34 (October, 1903).

the most important published contribution of Professor Gibbs to pure mathematics. For the vector analysis as an algebra does not fulfil the definition of the linear associative algebras of Benjamin Peirce, since the scalar product of vectors lies outside the vector domain; nor is it a geometrical analysis in the sense of Grassmann, the vector product satisfying the combinatorial law, but yielding a vector instead of a magnitude of the second order. While these departures from the systems mentioned testify to the great ingenuity and originality of the author, and do not impair the utility of the system as a tool for the use of students of physics, they nevertheless expose the discipline to the criticism of the pure algebraist. Such objection falls to the ground, however, in the case of the theory mentioned, for dyadics yield, for $n = 3$, a linear associative algebra of nine units, namely nonions, the general nonion satisfying an identical equation of the third degree, the Hamilton-Cayley equation.

It is easy to make clear the precise point of view adopted by Professor Gibbs in this matter. This is well expounded in his vice-presidential address on multiple algebra, before the American Association for the Advancement of Science, in 1886, and also in his warm defense of Grassmann's priority rights, as against Hamilton's, in his article in *Nature* "Quaternions and the *Ausdehnungslehre*." He points out that the key to matricular algebras is to be found in the open (or indeterminate) product (i.e., a product in which no equations subsist between the factors), and, after calling attention to the brief development of this product in Grassmann's work of 1844, affirms that Sylvester's assignment of the date 1858 to the "second birth of Algebra" (this being the year of Cayley's *Memoir on Matrices*) must be changed to 1844. Grassmann, however, ascribes very little importance to the open product, regarding it as offering no useful applications. On the contrary, Professor Gibbs assigns to it the first place in the three kinds of multiplication considered in the *Ausdehnungslehre*, since from it may be derived the algebraic and the combinatorial products, and shows in fact that both of them may be expressed in terms of indeterminate products. Thus the multiplication rejected by Grassmann becomes, from the standpoint of Professor Gibbs, the key to all others. The originality of the latter's treatment of the algebra of dyadics, as contrasted with the methods of other authors in the allied theory of matrices, consists exactly in this, that Professor Gibbs regards a matrix of order n as a multiple quantity in n^2 units, each of which is an indeterminate product of two factors. On the other hand, C. S. Peirce, who was the first to recognize (1870) the quadrate linear associative algebras identical with matrices, uses for the units a *letter pair*, but does not regard this combination as a product. In addition, Professor Gibbs, following the spirit of Grassmann's system, does not confine himself to one kind of multiplication of dyadics, as do Hamilton and Peirce, but considers two sorts, both originating with Grassmann. Thus it may be said that quadrate, or matricular algebras, are brought entirely within the wonderful system expounded by Grassmann in 1844.

As already remarked, the exposition of the theory of dyadics given in the vector analysis is not in accord with Grassmann's system. In a footnote to the address referred to above, Professor Gibbs shows the slight modification necessary for this purpose, while the subject has been treated in detail and in all generality in his lectures on multiple algebra delivered for some years past at Yale University.

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" (*Mem. Nat.*

Acad. Sci., vol. iv, pt. 2, pp. 79–104). The methods developed in this paper were afterwards applied by Professors W. Beebe and A. W. Phillips[2] 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' *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 simplicity 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

[2] Astronomical Journal, vol. ix, pp. 114–117, 121–124, 1889

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 supplied a more direct proof of its validity.

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 familar formulae of thermodynamics appear 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 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 methods 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 hypothesis 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 Poincare has said of Maxwell) that Gibba has not sought to give a mechanical explanation of heat, but has limited his task to de- monstrating that such an explanation is possible. And this achievement forms a fitting culmination of his life's work.

The value to science of Professor Gibbs's work has been formally recognized by many learned societies and universities both in this country and abroad. The list of societies and academies of which he was a member or correspondent includes the Connecticut Academy of Arts and Sciences, the National Academy of Sciences, the American Academy of Arts and 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.

Outside of his scientific activities, Professor Gibbs's life was uneventful; he made but one visit to Europe, and with the exception of those three years, and of summer vacations in the mountains, his whole life was spent in New Haven, and all but his earlier years in the same house, which his father had built only a few rods from the school where he prepared for college and from the university in the service of which his life was spent. His constitution was never robust — the consequence apparently of an attack of scarlet fever in early childhood — but with careful attention to health and a regular mode of life his work suffered from this cause no long or serious interruption until the end, which came suddenly after an illness of only a few days. He never married, but made his home with his sister and her family. Of a retiring disposition, he went little into general society and was known to few outside the university; but by those who were honoured by his friendship, and by his students, he was greatly beloved. His modesty with regard to his work was proverbial among all who knew him, and it was entirely real and unaffected. There was never any doubt in his mind, however, as to the accuracy of anything which he published, nor indeed did he underestimate its importance; but he seemed to regard it in an entirely impersonal way and never doubted, apparently, that what he had accomplished could have been done equally well by almost anyone who might have happened to give his attention to the same problems. Those nearest him for many years are constrained to believe that he never realized that he was endowed with most unusual powers of mind; there was never any tendency to make the importance of his work an excuse for neglecting even the most trivial of his duties as an officer of the college, and he was never too busy to devote, at once, as much time and energy as might be necessary to any of his students who privately sought his assistance.

Although long intervals sometimes elapsed between his publications his habits of work were steady and systematic; but he worked alone and, apparently, without need of the stimulus of personal conversation upon the subject, or of criticism from others, which is often helpful even when the critic is intellectually an inferior. So far from publishing partial results, he seldom, if ever, spoke of what he was doing until it was practically in its final and complete form. This was his chief limitation as a teacher of advanced students; he did not take them into his confidence with regard to his current work, and even when he lectured upon a subject in advance of its publication (as was the case for a number of years before the appearance of the *Statistical Mechanics*) the work was really complete except for a few finishing touches. Thus his students were deprived of the advantage of seeing his great structures in process of building, of helping him in the details, and of being in such ways encouraged to make for themselves attempts similar in character, however small their scale. But on the other hand, they owe to him a debt of gratitude for an introduction into the profounder regions of natural philosophy such as they could have obtained from few other living teachers. Always carefully prepared, his lectures were marked by the same great qualities as his published papers and were, in addition, enriched by many apt and simple illustrations which can never be forgotten by those who heard them. No necessary qualification to a statement was ever omitted, and, on the other hand, it seldom failed to receive the most general application of which it was capable; his students had ample opportunity to learn what may be regarded as known, what is guessed at, what a proof is, and how far it goes. Although he disregarded many of the shibboleths of the mathematical rigorists, his logical processes were really of the most severe type; in power of deduction, of generalization, in insight into hidden relations, in critical acumen, utter lack of prejudice, and in the philosophical breadth of his view of the object and aim of physics, he has had few superiors in the history of the science; and no student could come in contact with this serene and impartial mind without feeling profoundly its influence in all his future studies of nature.

In his personal character the same great qualities were apparent. Unassuming in manner, genial and kindly in his intercourse with his fellow-men, never showing impatience or irritation, devoid of personal ambition of the baser sort or of the slightest desire to exalt himself, he went far toward realizing the ideal of the unselfish, Christian gentleman. In the minds of those who knew him, the greatness of his intellectual achievements will never overshadow the beauty and dignity of his life.

H. A. BUMSTEAD.

Bibliography.

1873. Graphical methods in the thermodynamics of fluids. *Trans. Conn. Acad.,* vol. ii, pp. 309–342.

A method of geometrical representation of the thermodynamic properties of substances by means of surfaces. *Ibid.*, pp. 382–404.

1875–1878. On the equilibrium of heterogeneous substances. *Ibid.*, vol. iii, pp. 108–248 ; pp. 343-524. Abstract, *Amer. Jour. Sci.* (3), vol. xvi, pp. 441–458.

(A German translation of the three preceding papers by W. Ostwald has been published under the title, "Thermodynamische Studien," Leipzig, 1892; also a French translation of the first two papers by G. Roy, with an introduction by B. Brunhes, under the title "Diagrammes et surfaces thermodynamiques," Paris, 1903, and of the first part of the *Equilibrium of Heterogeneous Substances* by H. Le Chatelier under the title "Équilibre des Systèmes Chimiques," Paris, 1899.)

1879. On the fundamental formulae of dynamics. *Amer. Jour. Math.*, vol. ii, pp. 49–64.

On the vapor-densities of peroxide of nitrogen, formic acid, acetic acid, and perohloride of phosphorus. *Amer. Jour. Sci.* (3), vol. xviii, pp. 277–293; pp. 371–387.

1881 and 1884. Elements of vector analysis arranged for the use of students in physics. New Haven, 8^o, pp. 1–36 in 1881, and pp. 37–83 in 1884. (Not published.)

1882–1883. Notes on the electromagnetic theory of light. I. On double refraction and the dispersion of colors in perfectly transparent media. *Amer. Jour. Sci.* (3), vol. xxiii, pp. 262–275. II. On double refraction in perfectly transparent media which exhibit the phenomena of circular polarization. *Ibid.*, pp. 460–476. III.

On the general equations of monochromatic light in media of every degree of transparency. *Ibid.*, vol. xxv, pp. 107–118.

1883. On an alleged exception to the second law of thermodynamics. *Science*, vol. i, p. 160.

1884. On the fundamental formula of statistical mechanics, with applications to astronomy and thermodynamics. (Abstract.) *Proc. Amer. Assoc. Adv. Sci.*, vol. xxxiii, pp. 57, 58.

1886. Notices of Newcomb and Michelson's "Velocity of light in air and refracting media" and of Ketteler's "Theoretische Optik." *Amer. Jour. Sci.* (3), vol. xxxi,pp. 62–67.

On the velocity of light as determined by Foucault's revolving mirror. *Nature*, vol. xxxiii, p. 582.

On multiple algebra. (Vice-president's address before the section of mathematics and astronomy of the American Association for the Advancement of Science.) *Proc. Amer. Assoc. Adv. Sci.*, vol. xxxv, pp. 37–66.

1887 and 1889. Electro-chemical thermodynamics. (Two letters to the secretary of the electrolysis committee of the British Association.) *Rep. Brit. Assoc. Adv. Sci.* for 1886, pp. 388–389, and for 1888, pp. 343–346.

1888. A comparison of the elastic and electrical theories of light, with respect to the law of double refraction and the dispersion of colors. *Amer. Jour. Sci.* (3), vol. xxxv, pp. 467–475.

1889. A comparison of the electric theory of light and Sir William Thomson's theory of a quasi-labile ether. *Amer. Jour. Sci.*, vol. xxxvii, pp. 129–144.

Reprint, *Phil. Mag.* (5), vol. xxvii, pp. 238–253.

On the determination of elliptic orbits from three complete observations. *Mem. Nat. Acad. Sci.*, vol. iv, pt. 2, pp. 79–104.
Rudolf Julius Emanuel Clausius. *Proc. Amer. Acad.*, new series, vol. xvi, pp. 458–465.

1891. On the role of quaternions in the algebra of vectors. *Nature*, vol. xliii, pp. 511–513.

Quaternions and the *Ausdehnungslehre*. *Nature,* vol. xliv, pp. 79–82.

1893. Quaternions and the algebra of vectors. *Nature*, vol. xlvii, pp. 463, 464.

1893. Quaternions and vector analysis. *Nature*, vol. xlviii, pp. 364–367.

1896. Velocity of propagation of electrostatic force. *Nature*, vol. liii, p. 509.

1897. Semi-permeable films and osmotic pressure. *Nature*, vol. Iv, pp. 461, 462.

Hubert Anson Newton. *Amer. Jour. Sci.* (4), vol. iii, pp. 359–376.

1898–99. Fourier's series. *Nature*, vol. lix, pp. 200, 606.

1901. Vector analysis, a text book for the use of students of mathematics and physics, founded upon the lectures of J. Willard Gibbs, by E. B. Wilson. Pp. xviii + 436. Yale Bicentennial Publications. C. Scribner's Sons.

1902. Elementary principles in statistical mechanics developed with especial reference to the rational foundation of thermodynamics. Pp. xviii + 207. Yale Bicentennial Publications. C. Scribner's Sons.

1906. Unpublished fragments of a supplement to the "Equilibrium of Heterogeneous Substances." *Scientific Papers*, vol. i, pp. 418–434.
On the use of the vector method in the determination of orbits. Letter to Dr. Hugo Buchholz, editor of Klinkerfues' *Theoretische Astronomic. Scientific Papers,* vol. ii, pp. 149–154.

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B Lynde P. Wheeler: J. W. Gibbs in Heidelberg

We have even less information on the studies Gibbs pursued in the two semesters spent in Heidelberg in the year 1868–69 than for those of either of the two preceding years. An *Anmeldungs-Buch* for this year either was not issued or has been lost, and there are no notations on the prospectus, which has been preserved, to indicate which courses he actually attended. We only know (from the prospectus) that Kirchhoff, Hesse, Cantor, Rummer, du Bois-Reymond, and Eisenlohr were lecturing in courses on mathematics and mathematical physics; that Bunsen gave a course in experimental chemistry; and that Helmholtz lectured for the first semester in a sort of "orientation" course on the general results of the natural sciences, which was open to students from all of the faculties of the university. The work offered in mathematical physics appears to have been particularly comprehensive and, from the reputations of the lecturers, was presumably rich in content. But as to what part of this feast was enjoyed by Gibbs there is no evidence whatever. Neither have we any clue to the outside reading he did during this time.

We may however assume, without danger of going astray, that the general objectives of his study remained as they were in Paris and Berlin and that the work in Heidelberg suitably consummated the attainment of that perspective on the physical sciences and that insight into the possibilities for research which characterized all the rest of his career. One definite fact stands out from this whole period of European study, namely, that Gibbs cannot be regarded as the student of any *one* master. He undoubtedly gained inspiration from several, but from no one of them predominantly. In my own notes of his lectures in the 1890's I find reference to but one of his teachers of this time, Quincke, and that in regard to a very minor point. His real intellectual heritage stemmed from the masters of an earlier age, with whom however it is probably true that he first became intimately acquainted through his reading during these student days abroad.

About Gibbs' recreations during this sojourn in Europe we have only scattered recollections which have come down in the family. It is known that between terms he enjoyed short trips and it seems probable that he made excursions on horseback in the picturesque region around Heidelberg. It is also known that he took a few riding lessons at some time during the stay in Germany[8], and the most likely place would seem to have been in Heidelberg. Hastings in his biographical memoir[9] says that in later years Gibbs would in private conversation occasionally illustrate some point with examples from his personal experiences abroad, and relates one such from the Berlin days which shows that Gibbs had some social contacts outside of the lecture halls and reveals a sly appreciation of German intellectual condescension. But although he and his sisters must have enjoyed the usual amount of sight-seeing, concerts, opera, and theater, the record of this side of their experiences is very meager.

[8] "P.R.I.," contribution of W. G. Van Name.

[9] Charles S. Hastings, "Josiah Willard Gibbs," *Biographical Memoirs* (National Academy of Sciences, Washington, D.C., 1909), VI, 375–393. The story runs that in a conversation with Gibbs about the Connecticut Academy of Arts and Sciences one of his Berlin professors remarked that "its memberships appear to be pretty freely bestowed" if Gibbs himself were a member! Although it is true that the standards for admission to the academy were different from those prevailing in European academies, the implication that they were lower is hardly substantiated by the fact that the memoirs which brought-Gibbs lasting fame appeared later in its *Transactions*.

At the close of the second semester at Heidelberg Willard and Anna, after a short return visit in the spring of 1869 to the Riviera, returned to New Haven in June.

Quelle:
Wheeler, Lynde P.: Josiah Willard Gibbs : the history of a grat mind. — New Haven, Conn., 1951

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